AERIAL SPRAYING FOR GYPSY MOTH CONTROL: A HANDBOOK OF TECHNOLOGY

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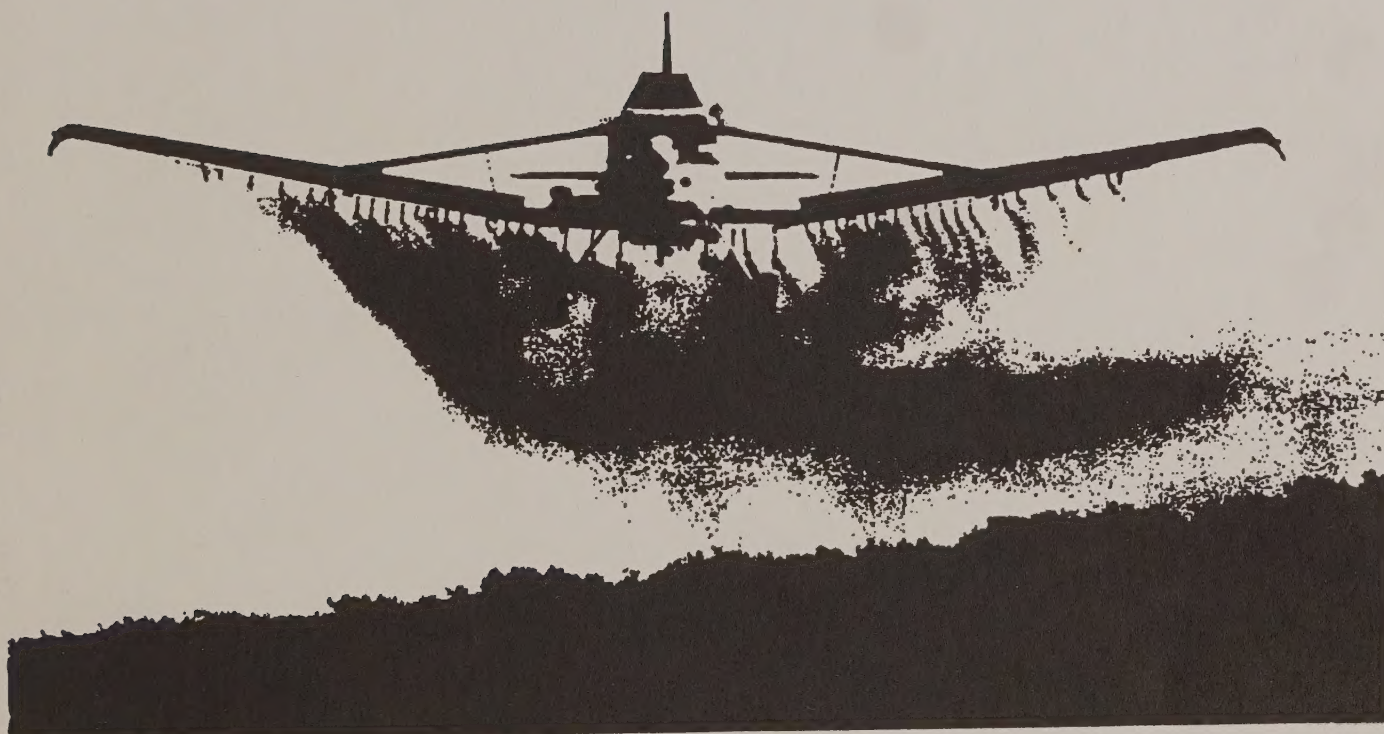

United States Department of Agriculture
Forest Service

Northeastern Area
Northeastern Forest Experiment Station

Northeast Forest Aerial Application Technology Group

N·E·F·A·A·T

AERIAL SPRAYING FOR GYPSY MOTH CONTROL: A HANDBOOK OF TECHNOLOGY

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Preface

This handbook is published as a part of the USDA Forest Service program to improve aerial application of insecticides, specifically to apply insecticides more effectively and efficiently to eastern hardwood forests. The program is supported through the efforts of the Northeast Forest Aerial Application Technology Group (NEFAAT). This Group is composed of members from the United States Department of Agriculture Forest Service, Northeastern Area State and Private Forestry (NA, S&PF), and Northeastern Forest Experiment Station, Research Work Unit 4502 and the Gypsy Moth Research and Development Program (NEFES); Animal and Plant Health Inspection Service (APHIS)-Science and Technology and Aircraft and Equipment Operations; and the Department of Entomology, Pennsylvania State University (PSU). Through cooperative efforts, the NEFAAT group conducts field and laboratory studies to solve common problems associated with insecticide application in eastern hardwood forests. It also provides technical assistance in conducting training sessions to improve the quality of operational programs involving the aerial application of insecticides.

This handbook is a summary of information presented at the Northeast Aerial Application Technology Workshop held at Pennsylvania State University, State College, Pennsylvania, September 23-25, 1986. The workshop was sponsored by NA, S&PF in cooperation with PSU and the APHIS. Members of NEFAAT developed the program for the workshop.

This handbook combines in a single publication relevant historical and current information concerning aerial application technology, specifically as it relates to gypsy moth control in broadleaved forests. Individual chapters were contributed by participants in the NEFAAT workshop. Their names and affiliations appear on page ii. A first edition of this handbook was published (August 1990) in a limited quantity (150 copies). Users' comments were incorporated into this updated version.

Jon Bryant and Karl Mierzejewski provided technical review of this undated version with subsequent technical reviews by: John Barry, USDA Forest Service-Forest Pest Management-Washington Office; Michael McManus, USDA Forest Service-Northeastern Forest Experiment Station, Hamden, Connecticut; Allan Bullard, USDA Forest Service-Appalachian Gypsy Moth IPM Project-Morgantown, West Virginia; and Tom Flanigan, USDA-Animal and Plant Health Inspection Service-Hyattsville, Maryland. Novo Biokontrol provided the conversion tables and definitions related to aerial application techniques (Appendix B).

The handbook's publication was supported by the Appalachian Integrated Pest Management (AIPM) Gypsy Moth Project, Northeastern Area, State and Private Forestry.

The use of trade, firm, or corporation names in this publication is for the benefit of the reader. Such use does not constitute an endorsement or approval of any service or product by the authors or by USDA Forest Service to the exclusion of others that may be suitable.

Information about pesticides appears in this handbook. Publication of this information does not constitute endorsement or recommendation by the U.S. Department of Agriculture, nor does it imply that all uses discussed have been registered. Use of most pesticides is regulated by State and Federal law. Applicable regulations must be obtained from appropriate regulatory agencies. **CAUTION**: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife if not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices given on the label for use and disposal of pesticides and pesticide containers.

Introduction

The gypsy moth, *Lymantria dispar* L., is a native pest of the forests of Europe and Asia that was introduced into the United States in Eastern Massachusetts in 1869 and in New Jersey in the 1920's. It is now established in all or parts of the 13 Northeastern States from western Pennsylvania, eastern West Virginia, and northern Virginia to central Maine, and extends into eastern Ohio and central Michigan. In Canada, this pest is established in southern Nova Scotia, Quebec, and Ontario. In addition to existing populations in the generally infested area, 68 isolated infestations have been eradicated since 1982.

The gypsy moth has been in periodic large-scale outbreak in the Northeast since 1926, most recently in 1980 lasting through 1983. During this period, over 28 million acres of forests were defoliated. At the present time, approximately 48 million acres of susceptible hardwood forests are occupied by the gypsy moth. Since the pest continues to spread both west and south into previously uninfested areas, the total area impacted by defoliation and subsequent tree mortality is increasing year by year.

Two types of control programs are in effect for gypsy moth: eradication projects, which take place outside the generally infested area and are designed to eliminate the target population, and suppression projects, which take place within the generally infested area and are designed to decrease adverse effects (e.g., defoliation, tree mortality, and nuisance). Both types of projects can involve multiple applications of biological or chemical insecticides.

Since 1980, the number of acres treated by insecticides and the type of insecticide used during cooperative Federal/State gypsy moth suppression projects have varied:

Insecticide Treatment For Gypsy Moth By Acres, 1980-1989

Year	Carbaryl	Bt[a]	Dimilin	Other[b]	Total	Percent of defoliated area treated
1980	18,517	16,963	0	44,814	80,294	12.5
1981	117,085	22,437	0	210,598	350,120	7.0
1982	160,242	67,324	77,918	421,246	726,730	5.6
1983	71,468	475,898	46,500	4,794	598,660	7.3
1984	37,040	229,909	252,769	4,072	523,790	21.9
1985	2,192	495,975	247,322	0	745,489	75.1
1986	8,755	413,225	350,992	0	772,972	45.2
1987	3,704	323,130	380,526	0	707,360	29.3
1988	0	287,120	506,112	48	793,280	59.6
1989	0	441,051	404,755	0	845,806	21.1

[a] *Bacillus thuringiensis*

[b] This category includes primarily Dylox and Orthene.

The effectiveness of these Federal/State cooperative suppression projects using the biological insecticide *Bacillus thuringiensis* (Bt) and, to a lesser extent, the chemical insecticide Dimilin, are monitored using a computer-based system (Treatment Monitoring Data Base) developed by Twardus. In general, the effectiveness of these projects has been highly variable. It is thought that a large portion of the treatment failures has been due to ineffective aerial application techniques.

Historically, application technology for forest spraying by aircraft was based on the techniques and equipment used for applying insecticides to agricultural crops. There were very few successes until the mid-forties, when a wide range of World War II aircraft sprayed DDT to control forest defoliators. DDT's effectiveness can be attributed to its persistence, which allowed maximum flexibility in application timing and techniques. Because DDT had proven so effective in controlling forest defoliators, aerial application technology for forest insecticides received little emphasis until DDT's general ban in 1972. In general, when the same aircraft and application techniques were used with less persistent insecticides, ineffective control was often the result.

As shown in the previous table, the nonpersistent insecticides Bt and Dimilin have been used almost exclusively since 1983 for cooperative gypsy moth suppression programs. Timing of insecticide application is extremely important for Bt (residual activity on foliage of 5 to 7 days) and to a lesser degree for Dimilin (residual activity on foliage for at least 30 days).

Moreover, growing environmental awareness has heightened public sensitivity to the potential hazards of insecticides in the environment, particularly when they are applied aerially over large areas and the potential exists for broad dispersal through drift.

Since operators have varying degrees of experience in planning and conducting cooperative suppression programs, this handbook is an attempt to present a comprehensive state-of-the-art guide to the relevant aerial application technology for insecticides in controlling gypsy moth. Hopefully, this information will provide a common basis for improving our ability to deliver insecticides more efficiently and safely to the forest.

CHAPTER I.

THEORY OF AERIAL SPRAY DEPOSITION AND SPRAY DELIVERY

1. Factors Affecting Droplet Dispersal and Distribution

Jon Bryant

Introduction

Control of insecticide deposition is vital if spray is to be delivered safely and effectively to its target. It is important for pest managers and aerial applicators to understand the physical factors that influence the flight of a liquid droplet from the aircraft to the forest canopy. Understanding how droplet physical phenomena, air disturbances caused by aircraft passage, the mixing of air passing over the canopy, and horizontal wind displacements shape spray distribution from aircraft allows for safe and target-specific application.

Droplet Size

Pesticide sprays are generally classified according to their droplet sizes. Droplet size is important to aerial applicators because it exerts a powerful influence over the transport and fate of a droplet. Size is one of the major application parameters that can be used to affect the droplet's path. A poor understanding of the effects of droplet sizes and the factors affecting droplet dispersal can lead to badly placed sprays, drift hazard, and unsatisfactory deposit results.

To get a clear mental picture of the size of various droplets, it is useful to compare typical spray droplet sizes with more familiar elements. Table I-1a gives examples for the normal range of droplet sizes that can be expected from aerial application. All sizes are given as diameters in microns (µm); 1 µm is the equivalent of 1 millionth of a meter (10-6), or 0.0000394 inches.

Table I-1a. Droplet sizes typical of aerially applied sprays and some comparisons with other liquid substances.

Droplet diameter (µm)	Comparable substance
600-1000	Moderate rain, minimum drift agricultural sprays
400-600	Coarse spray
200-400	Light rain, medium agricultural sprays
100-200	Drizzle, fine agricultural sprays
50-100	Mist
30	Cloud particles
10-20	Aerosol

The relationship between droplet volume and diameter (d) is expressed by the equation:

$$\text{Volume} = \frac{\pi d^3}{6}$$

Thus, doubling the diameter will increase a droplet's volume by a factor of eight. This means that a single 200 µm droplet has a volume eight times that of a 100 µm droplet. Alternatively, eight 100 µm droplets are needed to give the same amount of spray as a single 200 µm droplet, an important consideration when visually estimating deposits on spray cards or leaves.

Agricultural sprays contain a wide range of droplet sizes. Figure I-1 shows a typical distribution of these sizes for a hollow cone nozzle.

Figure I-1a represents the percentage of the total number of droplets in each number of size ranges. Each size range extends over approximately 30 µm. Clearly, most droplets are produced in the lower size range. A quick inspection shows approximately 41 percent of the total number produced is in the first two size classes alone (less than 100 µm). The transformation between percent number (Fig. I-1a) and percent volume (Fig. I-1b) requires multiplying the number of droplets in each size class by the average droplet volume in that size class. This shows that what first appeared to be a startling 41 percent of the spray droplet number in the highly driftable 100 µm and below size range actually contributes a minute fraction of the total spray volume. The percent-volume graph (Fig. I-1b) clearly shows that, in this example, the vast proportion of the total volume is actually atomized in the 200-600 µm size range.

It would be an impossible task to describe a range of sizes (for example, those collected on a spray card) without the aid of some form of statistical measurement. The two most widely used measures are the number median diameter (NMD or Dn.5) and the volume median diameter (VMD or Dv.5). The median value divides the spray in half--it is not an average or mean measure. So, for the Dn.5, the spray is divided to give 50 percent of the total number of droplets above this size threshold and 50 percent below. For the Dv.5, the spray is divided in terms of its volume -- 50 percent above the Dv.5 and 50 percent below (see Fig. I-1c).

But a Dv.5 alone cannot provide a measure of the width or range of droplet sizes in a droplet spectrum as demonstrated in Figure I-1d. In this case, both spectra have the same VMD, but the composition of each, or range of droplet sizes present, is clearly very different and would behave very differently in the field. There are two generally used methods for presenting an estimate of the spectrum width that use the ratio of two or more measures of the spectrum. The first is the Relative Span:

$$RS = \frac{Dv.9 - Dv.1}{Dv.5}$$

where Dv.9 = the droplet size that divides the spray such that 90 percent of the volume lies below and 10 percent above this size, Dv.5 = the droplet size that divides the volume 50 percent on either side of this size, and Dv.1 = the droplet size that divides the spray such that 10 percent of the volume lies below and 90 percent above that size. A value of zero would represent a mono-sized spray. The more usual value is around one. The second measure of spectrum width uses both the Dv.5 and Dn.5 presented as a ratio of Dv.5 divided by Dn.5 the R value, which will range from a value of one for a mono-sized spray, three to five for a narrow spectrum rotary atomizer, and up to ten for conventional hydraulic nozzles.

While we do not yet know the ideal droplet size for maximum deposit under a wide range of field conditions for the hardwood forest, we do know the droplet sizes that are of little contribution and should be avoided by careful selection of nozzle size and operating pressure. Large droplets (>500 µm) contain a disproportionate amount of the total spray volume for the biological effect they impart. There are theoretical arguments to suggest that small droplets would be best for control. The diameter-to-volume relationship (page 5) means that relatively small reductions in droplet size can greatly increase the number of droplets produced from a given volume of spray. Figure I-1e, adapted from Lewis (1983), illustrates this point with a series of hypothetical deposits from 1 gallon of liquid atomized into sprays of different sizes.

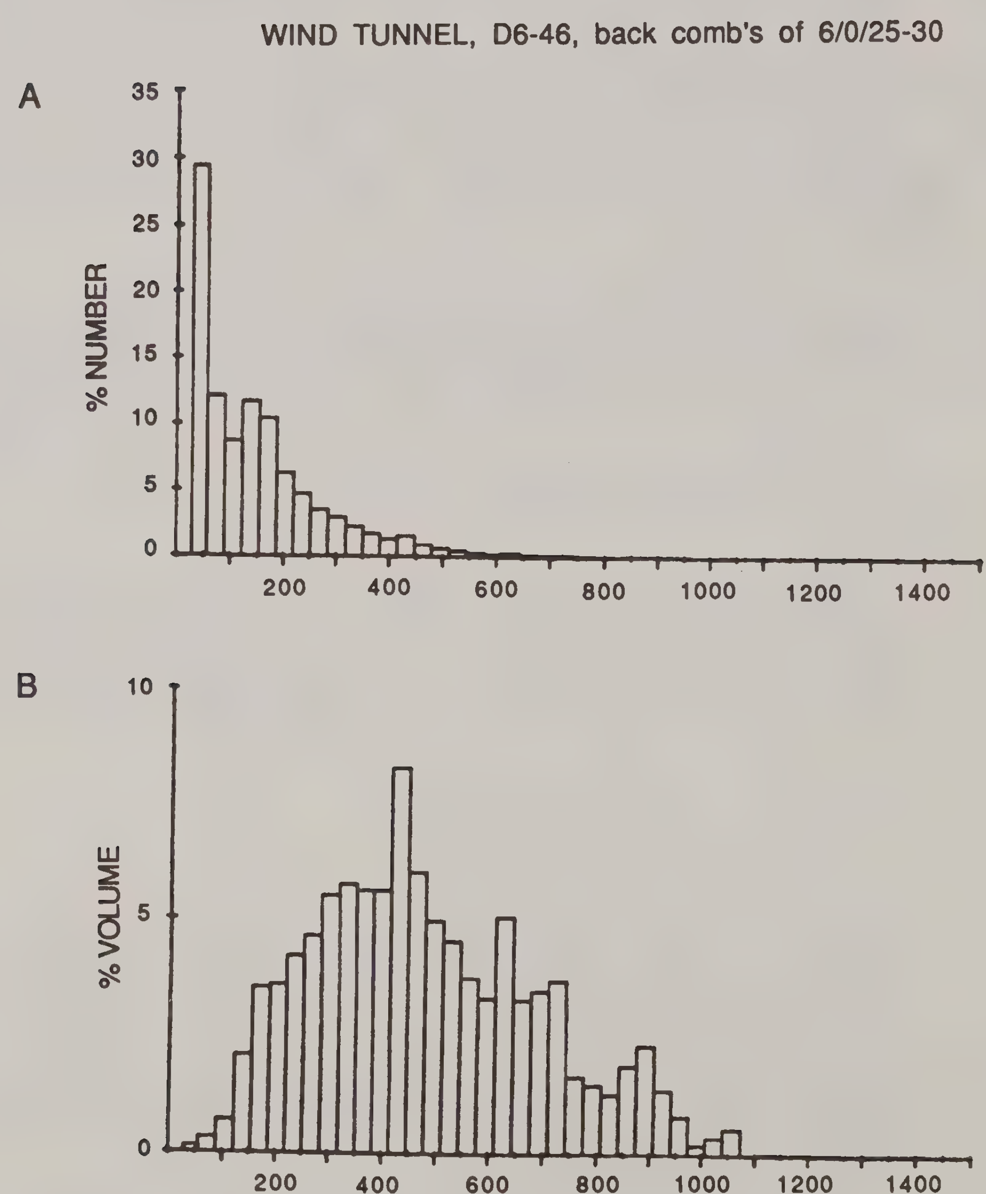

Figure I-1a and I-1b. Distribution of dropsize by (a) number and (b) volume in an aerial spray from a hollow cone nozzle (D6-45). (Source: Ekblad and Barry 1983).

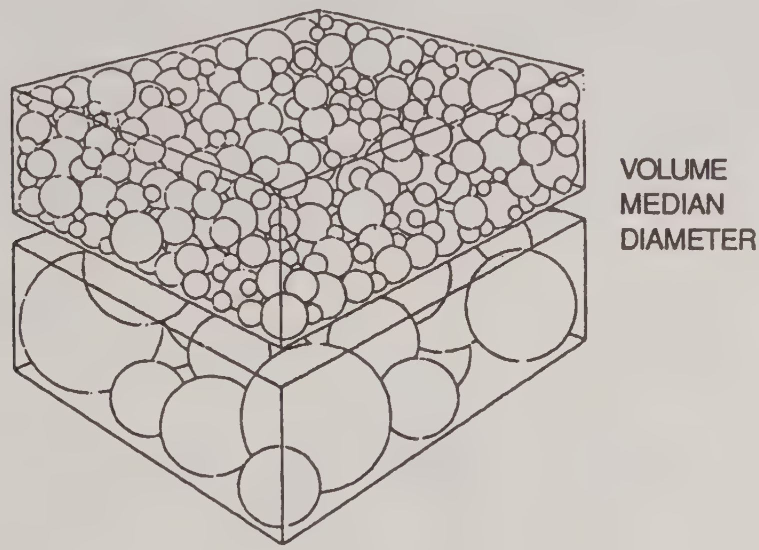

Figure I-1c. Division of a spray to show a volume median diameter. (Source: O'Neal and Brazelton 1984).

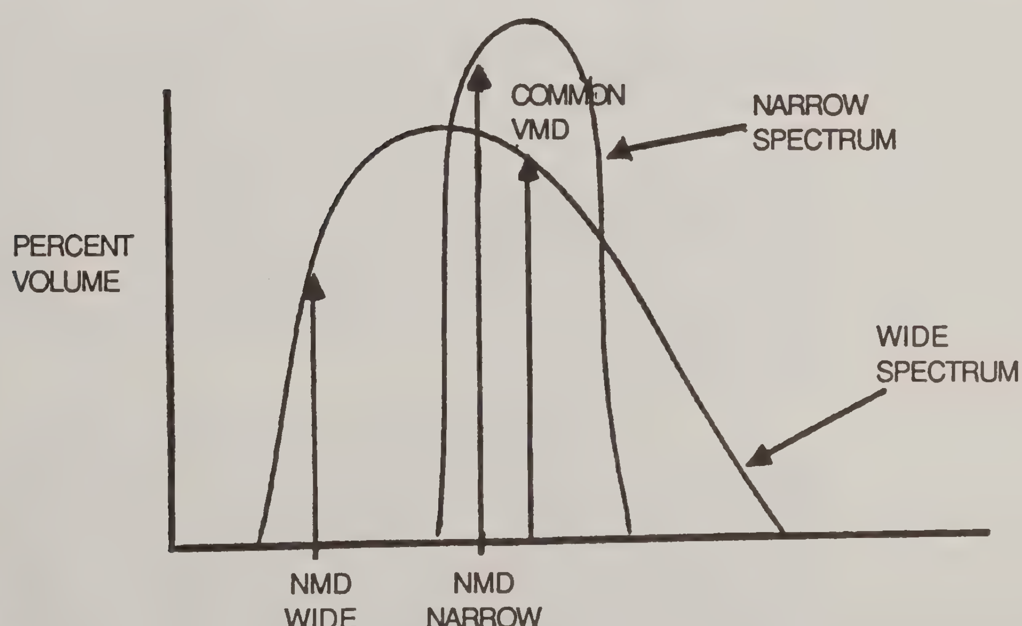

Figure I-1d. A comparison of droplet spectrum composition from spray with a common volume median but different number median diameter. The vmd alone does not describe the composition of the spectrum of these droplets without additional information such as the nmd.

Figure I-1e (top) represents deposit on a flat surface of 1 cm² area assuming no losses; Figure I-1e (bottom) shows the reduced deposit density from an increase in target area to 3 cm² of leaf for every 1 cm² of ground for a hardwood forest. The inset square represents the leaf area eaten by a single second instar gypsy moth in 24 hours.

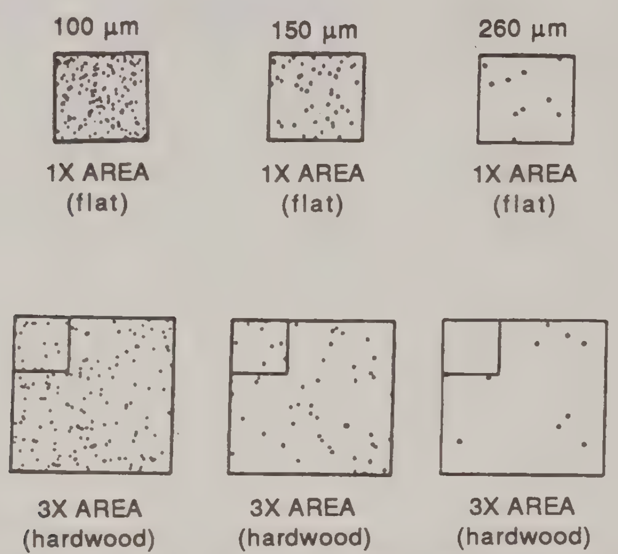

Figure I-1e. Spray distribution from sprays of different droplet sizes from 3.9 l/ha (1 gal/ac). The top series represents the deposit in a flat surface and the bottom series the deposit in a hardwood forest with a leaf area index of 3.

The smaller-size-droplet spray clearly produces more droplets from the same initial volume of liquid than the large spray and is thus likely to make more droplets available for capture. This fact has been reflected in the higher density of droplets (number/cm²) from our theoretical ground deposition. The importance of this increase becomes more obvious when the effect of the canopy is considered. It has been estimated that for every acre of ground there is approximately 3 acres of foliage. So, when we spray 96 fluid oz per acre of ground, we also mean 96 fluid oz per 3 acres of foliage. This will reduce the deposit per unit area if each leaf is equally covered as shown in Figure I-1e (bottom). In summary, the use of a small droplet spray gives many more droplets, which may increase the foliage coverage. However, the presence of foliage means that the deposit applied is spread over a leaf area larger than just the ground covered, thus reducing average deposit on the leaves.

Small droplets of 100 µm and less prove difficult to control to produce a reliable swath width and safe insecticide distribution and are liable to lose volatile components quickly through evaporation. Small droplet (approximately 50-100 µm) application techniques are used for coniferous forest spraying in Canada. However, the advantages in this situation are that thousands of acres may be sprayed in a single block, less frequent conflicts exist with human habitation, and the small coniferous needle is a highly efficient catching surface for the small droplet size. With these advantages in mind, a totally different set of applications and safety criteria is needed when spraying for gypsy moth in urban regions and small blocks in the Northeastern United States. But can these small droplets be applied safely? Clearly, the whole application system is composed of a series of steps, from the droplet leaving the nozzle to its impaction on the leaf. These steps and factors, which prevent us from achieving the ideal deposit distribution, are considered in the following discussion.

Droplet Behavior Before examining the behavior of a spray cloud, the behavior of single droplets under simple conditions needs to be explored. If a droplet (say, of 200 μm) is released into still air, it will start to fall, accelerating under the pull of gravity. As a parachutist can confirm, a falling object does not continue accelerating through the sound barrier. Instead, as the object begins to fall, moving relative to the stationary surrounding air, it begins to feel the restraining pull of the air's resistance, or drag. As the velocity increases, so does the drag (see Fig. I-1f). Fortunately for the parachutist and the aerial application scientist, a point is reached where the drag force restraining the object's fall will equal the gravitational force pulling it down, and velocity no longer increases.

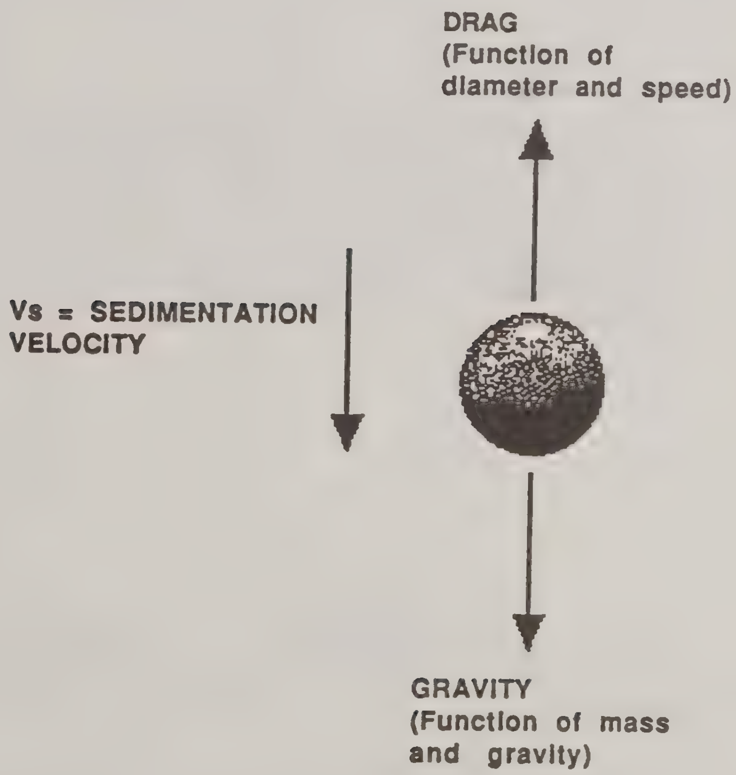

Figure I-1f. Forces acting on a falling spray droplet.

The droplet's velocity at this point is termed the sedimentation or terminal velocity and is the maximum speed of fall relative to the surrounding air. For the parachutist, terminal velocity occurs at around 150 mph, but for our 200 μm droplet, this occurs at a leisurely 85 cm/sec, or 33.5 in/sec. Table I-1b shows the sedimentation velocities for droplets in the spray droplet size range. A general estimate of sedimentation velocity can be obtained from the relationship:

$$\text{Sedimentation velocity} = 0.003 \times \text{diameter}^2$$

where velocity is given in cm/sec and diameter is given in microns. This relationship holds for small droplets but overestimates velocity for large droplet sizes.

Table I-1b. Sedimentation velocity of free-falling droplets.

Droplet size (µm)	Terminal velocity (Feet/sec)	(M/sec)
50	0.3	0.09
100	0.9	0.27
150	1.9	0.58
200	2.8	0.85
300	4.4	1.34
500	6.9	2.10
1000	13.1	3.99

Horizontal Spray Displacement

It is important to remember that a droplet's motion is relative to the surrounding air. If the surrounding air is displaced upward at the same speed as the droplet's downward sedimentation velocity, the droplet would appear stationary relative to an observer on the ground. This concept can also be applied to a horizontal air movement. Figure I-1g shows a droplet falling in air, but the air is moving horizontally. The combination of these two movements would give the droplet an inclined path relative to an observer on the ground.

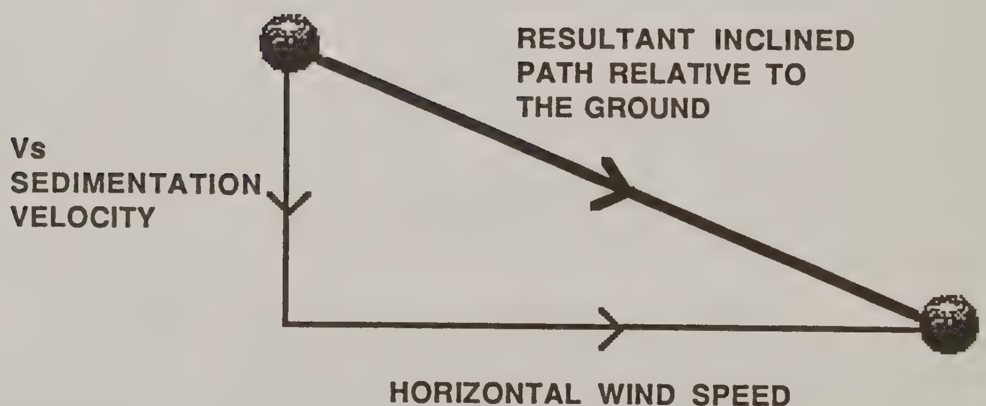

Figure I-1g. Inclined path of a single droplet resulting from the combination of vertical sedimentation velocity and horizontal displacement by the wind. The resultant path shows an incline relative to an observer on the ground.

Consider the example of a 100 µm droplet with a sedimentation velocity of just 27 cm/sec (0.9 ft/sec) falling in a wind speed of 300 cm/sec (9.8 ft/sec). If the droplet were released from 50 feet, it would theoretically take 56 seconds to reach the canopy and would have been displaced laterally by the wind a distance of 555 feet from the point of release. It now becomes clear that a basic picture of downwind displacement can be obtained by considering droplet diameter, hence, vertical sedimentation velocity, horizontal wind velocity, and height of release by the aircraft. The following expression approximates this relationship:

$$\text{Downwind travel} \sim \frac{\text{Release height (ft)} \times \text{Wind speed (mph)} \times 1.47}{\text{Sedimentation velocity (ft/sec)}}$$

As a more complex (but more realistic) picture of the atmosphere is evolved later in this handbook, it will be obvious why droplets are often brought to earth sooner than this simplified relationship suggests. This relationship is described further in Table I-1c.

Table I-1c. Theoretical downwind displacement (feet) of a single spray droplet released into a horizontally moving airflow at a height of 50 feet.

Droplet size (µm)	Horizontal wind speed (mph) 2	4	10	20
50	496.0	992.1	2480.2	4960.5
100	165.3	330.5	862.3	1652.5
200	52.4	104.9	262.2	524.5
500	21.4	42.8	106.9	213.9
1000	11.1	22.3	55.7	113.0

Air Movements Influencing Droplet Dispersal

The picture so far is one of simple and predictable relationships governing the fate of a droplet. This is not the case in the field where many varied air movements influence droplet behavior. These movements have been classified into three categories:

- Turbulence caused by surface roughness that mixes the layer of air above the canopy extending up to about 1,000 feet. This condition is especially prevalent over the rough and uneven surface of a forest canopy.
- Horizontal winds of varying strength and direction caused by large-scale convective effects and prevailing wind.
- Upheaval caused by the passage of the aircraft leaving a vortex wake.

Thus, the droplet is going to pass through many varied air movements, not a single smooth airmass. The influence of these air movements on the droplet's fate will depend on the relative magnitude of two factors: first, the vulnerability of the droplet to being caught in the moving airmass and moved from its present descending path (this factor is related to sedimentation velocity, and hence, droplet size); second, the extent of the disturbing forces of the surrounding air movements on the droplets.

Intuitively, it might be expected that a large, fast-falling droplet is less prone to being moved by the effects of an accelerating airmass than a small droplet would be. This is indeed the case. Conversely, small droplets, which have a low mass and low sedimentation velocity, are readily carried within moving air-vertically or horizontally. This means that droplets will deviate from a vertical path to the ground, depending on the relative size of the first and third factors described above, and will be displaced in the general direction of the wind mentioned in the second factor. The effect of each of these sources of air movement and the dispersal of a droplet cloud are discussed in the following section with reference to different droplet size clouds.

Surface roughness mixing. The turbulence caused by surface roughness is random and increases in scale with height above the surface. These random, three-dimensional air movements will extend a spray cloud in all directions. Envision a point release of uniformly sized droplets into a crosswind at some height above the canopy. The passage these droplets would take, shown in Figure I-1h, is an expanding cone of droplets. Droplet concentrations would be dilute at the edge of the plume with increasing concentrations near the center. Also, average droplet concentration would decrease further from the point of emission. A cross-sectional slice through this cloud would reveal the bell-shaped (or Gaussian) distribution of droplet concentration shown.

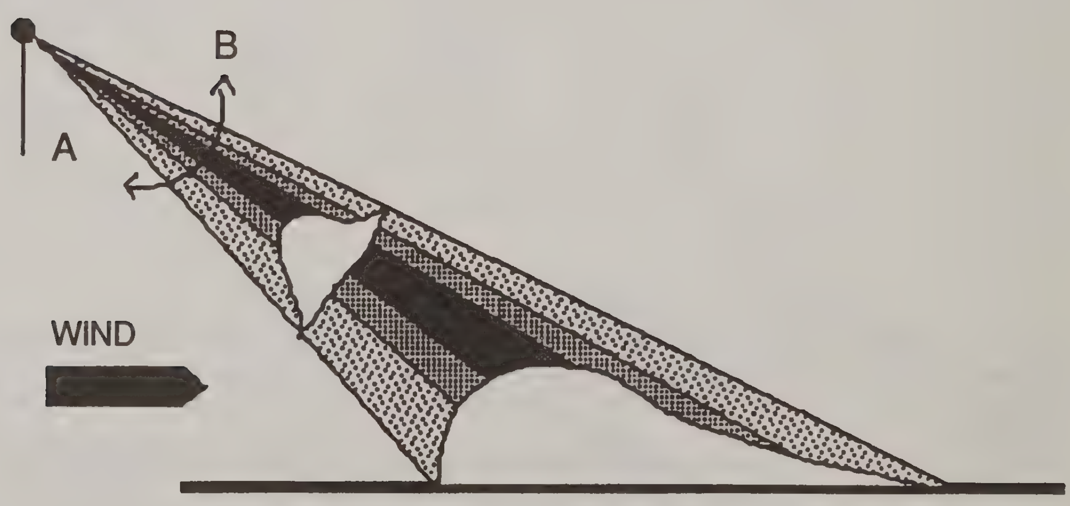

Figure I-1h. Dispersal of spray cloud by random air turbulence and displacement by a horizontal wind. Angle A depends on the ratio of the sedimentation velocity and the wind velocity. Angle B depends on the intensity of the turbulence and the droplet size.

Figure I-1i shows the dispersal of two droplet clouds--one containing large droplets insensitive to the perturbation of surrounding air, the other containing small droplets more readily moved by the changing air conditions. It can be seen that the big droplet path is less affected during its relatively short fall time by the same horizontal wind and the same level of random turbulence. Also, lateral displacement and dispersal are reduced in comparison to the small droplet. In practice, given the range of droplet sizes shown previously, the final droplet deposit pattern is a combination of these patterns for each droplet size in the spectrum.

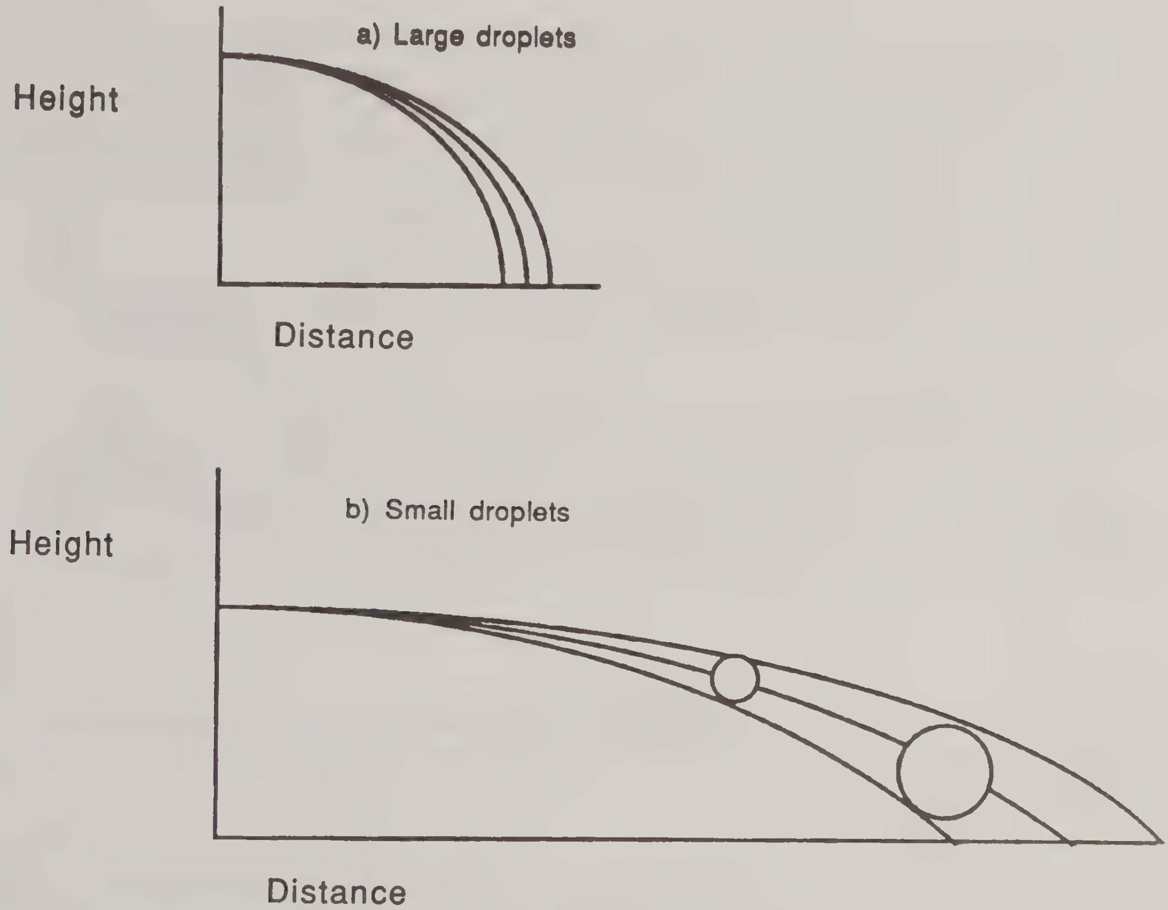

Figure I-1i. Droplet cloud dispersal from two droplet sizes under identical turbulence and wind speed conditions, showing mean descent path and the extent of cloud spread.

Horizontal wind movements. Just as a horizontal wind displaces a single droplet in our simple model, the droplet cloud is displaced downwind with a mean descent path roughly equivalent to the single droplet, no-turbulence path. Declining horizontal wind velocity with decrease in height, as discussed in later chapters, produces the curved descent paths shown in Figure I-1i. The deposit pattern when this cloud reaches the ground is that of a skewed bell shape, depending on the mean angle of the fall path and the intensity of the turbulence. Comparing the mean path of this cloud, which is equivalent to a no-turbulence case, to the final spread of the deposit, we see that the spray has been spread both vertically and horizontally by the turbulence.

Aircraft wake movements. The final disruptive factor to be considered in droplet dispersal is the effect of aircraft wake. Aircraft wake is the predominant force shaping droplet movement in the first stages of dispersal. The passage of both fixed-wing aircraft and helicopters at cruise speeds (>45-55 mph) leaves pairs of vortices, or rolled swirling airmasses, in the air behind the aircraft. These vortices are shed from just inboard of the tip of all lifting aerofoil surfaces. The resulting air movement in the path of the aircraft is shown in Figure I-1j for a fixed-wing aircraft (left) and for a helicopter (right) operating at cruise conditions in the vicinity of the ground.

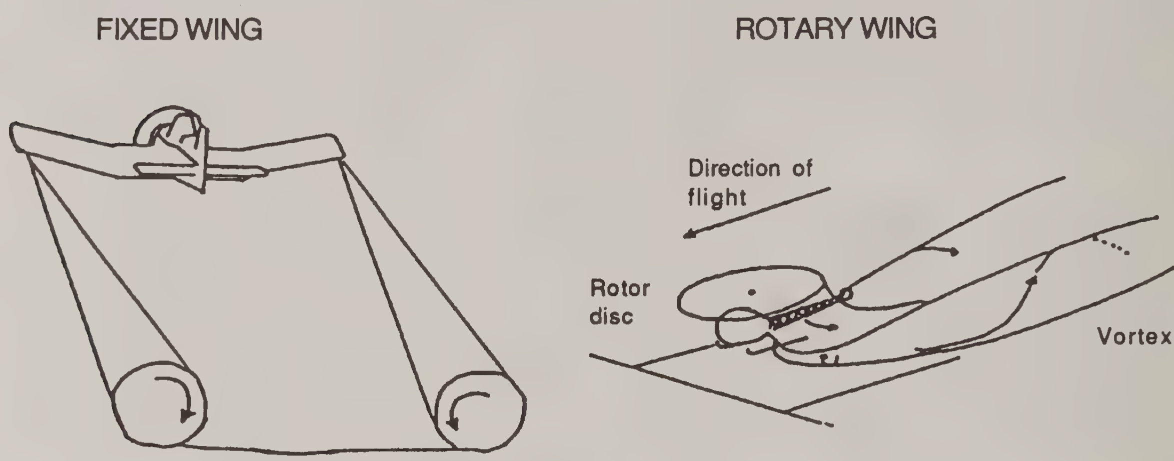

Figure I-1j. Trailing vortex patterns of fixed wind aircraft (left) and helicopters (right) flying under cruise conditions.

The vortices are induced by the air movement and pressure patterns needed to maintain lift over the wing surface. The problem arises at the tips of the aerofoil surface. The pressure differences above and below the wing cannot be maintained without the physical presence of the aerofoil or wing. The resulting redistribution of air moving from the relatively higher pressure under the wing to low pressure on top of the wing gives the flow patterns shown in Figure I-1k and leads to vortex formation.

Figure I-1k. Airflow pattern at the wingtip of a lifting aerofoil. (Source: Spillman 1980a).

The velocities induced in these vortices are easily strong enough to entrain small- and even medium-sized droplets. The National Aeronautical and Space Administration has recorded air velocities of 13 m/sec, or almost 30 mph, in the vortex, which is far beyond the sedimentation velocity of even large droplets. The general path of the vortex and those droplets entrained from the inboard section is downward and outward, especially near the ground. However, with time, the friction of the surrounding air will erode the strength of the tip vortices, and dispersal by the normal turbulent processes discussed previously will begin to dominate droplet dispersal. It is the spread of these airmasses that causes swath widths to be greater than the wingspan of the aircraft. Because it is the small droplets most readily entrained in this spreading airmass, droplet size is often found to decrease away from the swath's center.

Droplets entering the outboard section of the vortex pose the greatest problem. These are swept up above the wing. From this position, they require a longer time to travel to the ground, increasing the evaporation and drift risk (see Fig. I-11). The nozzles placed near the wingtip and in this vortex region are not generally thought to contribute significantly to swath width improvements. For this reason, aerial applicators generally do not place nozzles in the boom positions past approximately the 3/4 semispan position.

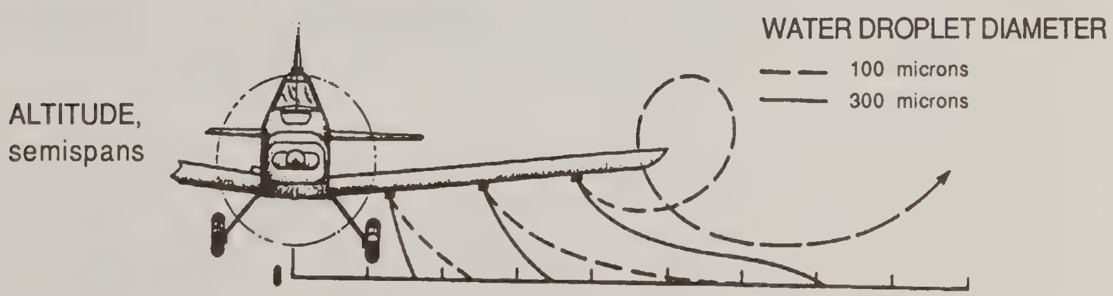

Figure I-11. General path of droplets under the influence of the aircraft wake. (Source: Jordan et al. 1978).

Propeller slipstream, the spiral core of air around the fuselage from the propeller, will also disrupt the spray swath (see Fig. I-1m). Lateral displacement can usually be compensated for by careful nozzle positioning during the characterization phase of the trial. As with turbulent air movement, it is the droplet size that governs the magnitude of the effects of propeller and wing-tip vortex disturbances on the path of the droplet near the aircraft. The path of a droplet can be predicted using computer models. The series of illustrations in Figure I-1n shows the effect of propeller and wing-tip vortex effects on a range of five droplet sizes from a spray with an overall VMD of 320 µm. The large droplet size (1,300 µm) falls directly beneath the aircraft, slightly affected by the air disturbance. Almost no noticeable swath extension is seen above the width of the boom, and only slight lateral disturbance is caused by the propeller. However, the smaller droplet sizes become progressively more influenced by the air disturbances. Droplets in the vortex vicinity are displaced outward to provide an extended swath above the width

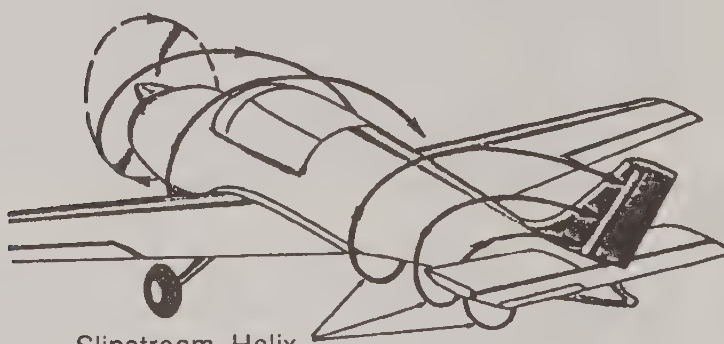

Figure I-1m. Airflow around the fuselage of an aircraft caused by the propellor.

of the boom. But droplets are removed from beneath the aircraft and displaced to one side. The resulting theoretical ground deposit has very similar characteristics to the deposit patterns found in characterization trials, namely, a tapering extended deposit pattern and a deposit peak caused by the spray dumped to one side of the fuselage by the propeller.

Airborne Spray Evaporation

The basic models described previously have all assumed that the droplet size remains constant on its path to the impaction site. This assumption is unreasonable if there are volatile components in the spray that can evaporate and reduce the volume (hence, diameter) of the droplet. The droplet spectrum that leaves the nozzle and would be measured during a wind tunnel trial is unlikely to be the same spectrum that reaches the forest canopy. As the sedimentation examples show, the airborne duration of droplets released at 50 feet above a canopy can extend into minutes. During this period, the volatile fraction of the spray will evaporate at a rate mainly governed by the volatility of the material, the air temperature, and the relative humidity. The problem is especially acute for small droplets.

Table I-1d demonstrates the expected change in droplet diameters over time under a range of environmental conditions for water. The table gives the distance (in feet) a droplet would fall until all water has evaporated and the time period (in seconds) to this point of extinction. This shows that under both meteorological conditions, a droplet less than 100 µm would not reach the canopy if released at 50 feet. The increase in temperature and the increase in the separation of the wet and dry bulb temperatures (T°C) (a decrease in relative humidity) both serve to quicken the evaporation rate and reduce the time period to droplet extinction. Airborne evaporation places more droplets at risk from drift and loss from the target zone than would be expected from a droplet spectrum taken from the nozzle itself.

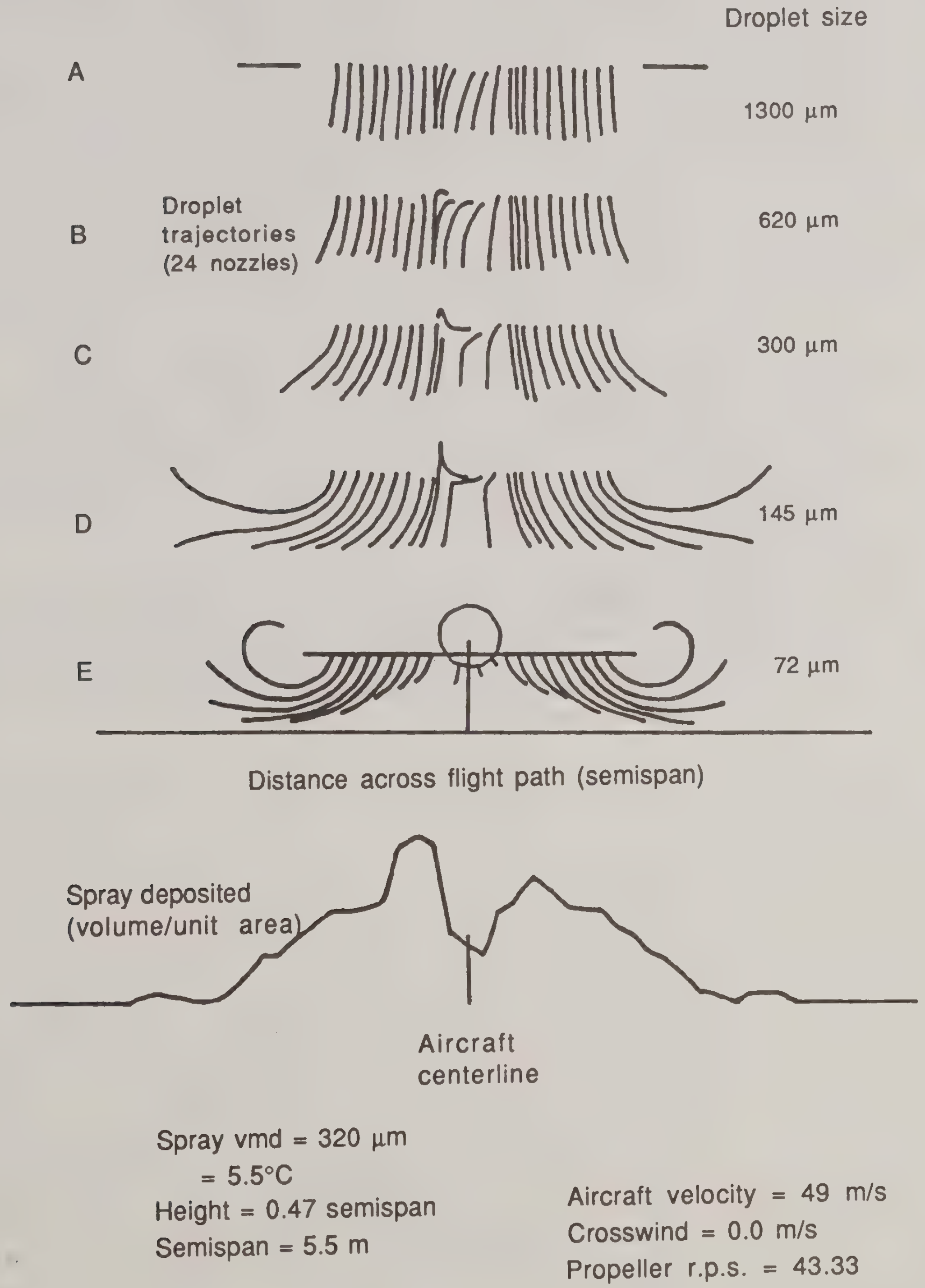

Figure I-1n. The influence of droplet size on the behavior of a droplet in the wake of a fixed-wing aircraft. (Source: Trayford and Welsh 1977).

Table I-1d. Evaporation rate for water droplets under various environmental conditions.

	Temperature (°C) 20 ΔT (°C) 2.2 [a] Relative humidity(%) 80		Temperature (°C) 30 ΔT (°C) 7.7 [a] Relative humidity(%) 50	
Initial droplet size (µm)	Lifetime to extinction (Seconds)	Fall distance (Feet)	Lifetime to extinction (Seconds)	Fall distance (Feet)
50	14	1.64	4	0.49
100	57	27.90	16	7.90
200	227	447.50	65	128.00

[a] ΔT refers to the difference between wet bulb and dry bulb temperatures.

Source: Matthews 1980.

The effects of evaporation can be seen during aircraft characterization trials under different meteorological conditions. Figure I-1o shows the result of two separate characterizations of the same aircraft applying the same material (Dipel 8L diluted in water) with the same equipment. The difference in the scale of recovery is due mainly to the effects of evaporation.

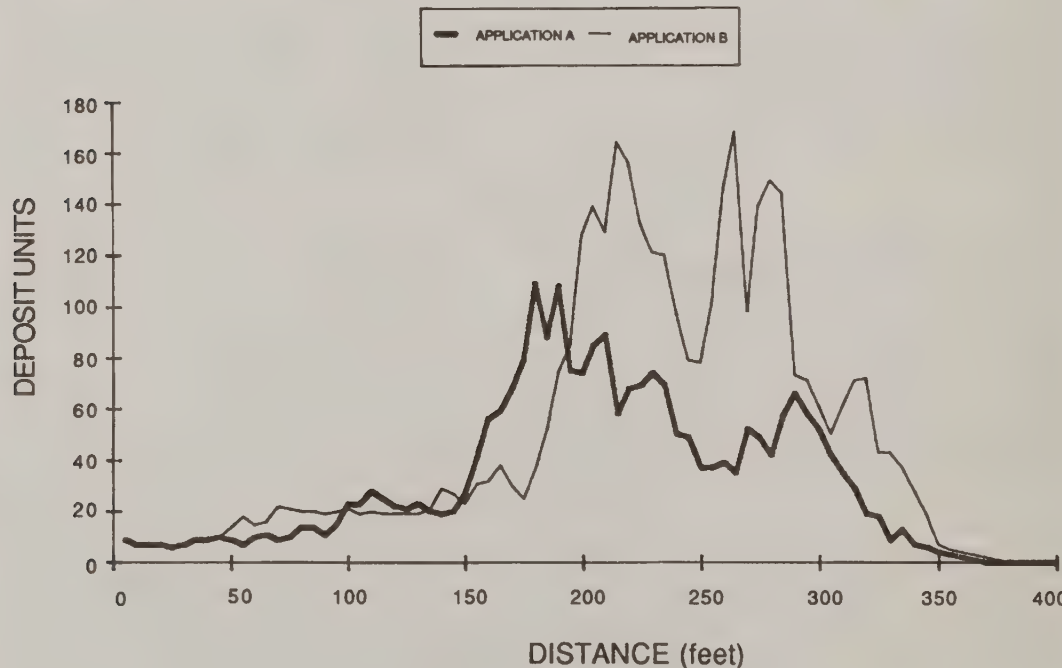

Figure I-1o. A comparison of the effect of microclimate on deposition. Pattern A was made with a 6.2 mph (3.1 m/sec) wind from 8 degrees to the right of the flight line at 23.3°C and 44 percent RH. Pattern B was made with 8.6 mph (4.3 m/sec) wind from 4 degrees to the left of the flight line with 11.2°C and 87 percent RH. Both curves are a mean of three characterization lines.

There are ways to minimize evaporation or at least its effects:

- Avoid meteorological conditions that will exacerbate the evaporation problem. High evaporative loss can be expected from application in temperatures above 80°F and relative humidity less than 50 percent. Below these thresholds, evaporation can still be a problem, especially if application heights are excessive, or formulations are mainly water. Spraying effectiveness can be checked by ground crews using deposit cards to ensure droplets are reaching the ground under the prevailing weather conditions.

- Use materials with either low volatility (e.g., oil carriers) or additives that reduce the rate of evaporation from the surface of the droplet, usually by an encapsulation process.

- Finally, use nozzles that produce droplet sizes that are not seriously affected by evaporative losses. This means increasing droplet size, which gives a two-way attack on the evaporation problem: First, we now know that a large droplet with its higher sedimentation velocity will reach the target in a relatively short time and thus leave less time available for airborne evaporation. Second, the surface area-to-volume ratio is less for a large droplet than for a small one. This is important because the droplet surface area governs rate of liquid loss, and thus large droplets tend to lose diameter less quickly through evaporative loss than small droplets. Figure I-1p demonstrates this principle. In practice, a compromise is sought between increasing the droplet size to give low evaporative losses and keeping droplet numbers high enough to maintain toxic levels of deposit density in the canopy.

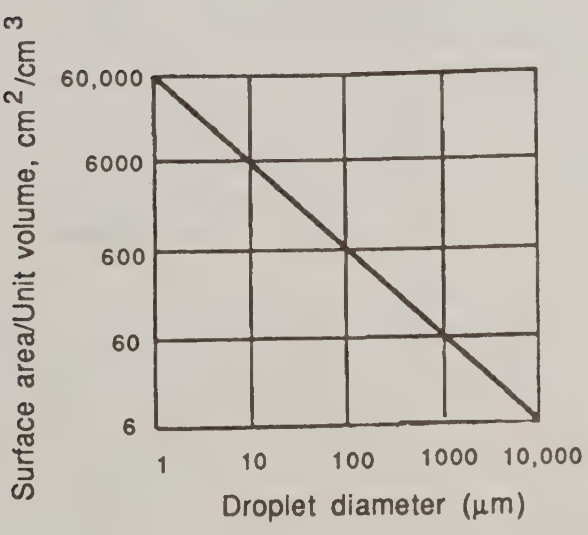

Figure I-1p. Relationship between the surface area-to-volume ratio, a major determinant in the rate of evaporative loss in droplet volume, hence, droplet diameter. (Source: Matthews 1982).

Examples of Spray Dispersal Systems

As established earlier, the combination of these three main factors -- roughness/ turbulence, horizontal wind, and aircraft wake--form a complex system of interactions (see Fig. I-1q). To demonstrate the deposition system, we can examine two application systems that differ according to the direction of flight with respect to the prevailing wind.

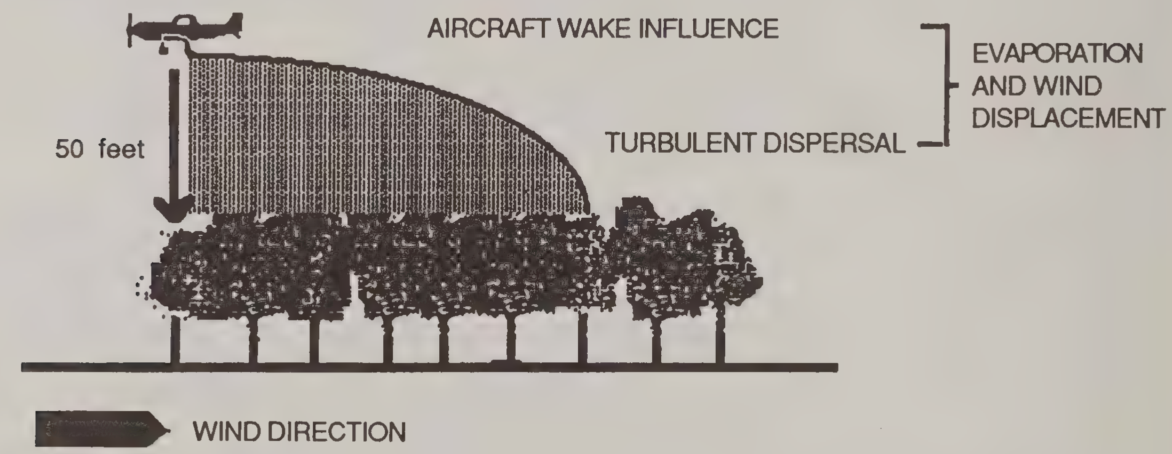

Figure. I-1q. Combination of aircraft wake, turbulence, and horizontal wind, which form the major components of a droplet dispersal system.

Example 1: flight into wind; VMD 250 mm. Aircraft characterization by flying into wind provides a conservative estimate of swath width because the only factors in this dispersal system for extending the lateral spread of the swath come from the aircraft wake plus any random horizontal component imparted through turbulence (see Fig. I-1r). These influences are likely to be small in relation to the potential spread of the swath we shall see in the following crosswind example.

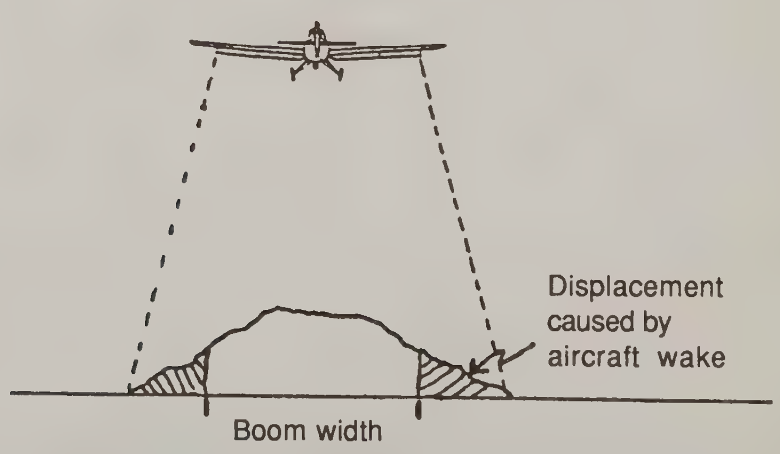

Figure I-1r. Distribution of spray from a flight line into wind. Note the extended swath caused by the aircraft wake.

Droplets released into a head- or tailwind move at an inclined path relative to the ground and with an angle dependent on the ratio of sedimentation velocity to wind speed. But this movement will be in the direction of the flight line, not laterally to the downwind side of the aircraft. Failure to recognize this can cause problems with spray placement and drift. Figure I-1s shows how pilot failure to recognize these effects can lead to both missed treatment area and spray drift outside the treatment block, potentially into sensitive habitable regions.

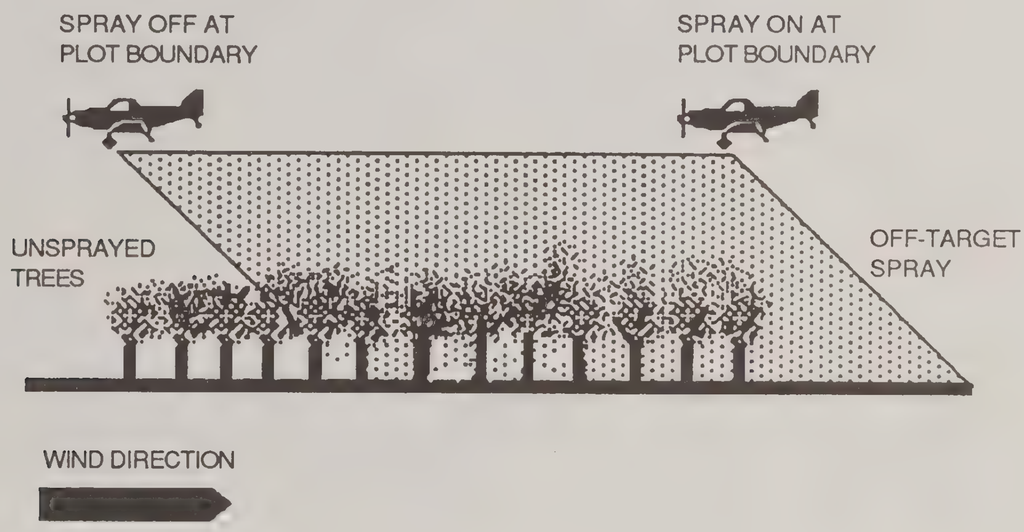

Figure I-1s. Spray displacement out of a spray area during flight into the wind. Although nozzles are switched on at the plot boundary, the final deposit is displaced outside the plot by the horizontal wind component.

This effect can be minimized by the careful on-and-off operation of the spray system in an attempt to compensate for the displacement. The release height also plays a role in determining droplet displacement, and although it may not be possible to reduce the application height for safety considerations, it is necessary to ensure that the aircraft does not release spray above the predetermined height of, say, 50 feet.

In practice, it is most unlikely that an application can be made directly into the wind, either because of changes in direction while spraying a block or practical limitations of shape and orientation restricting flight into the wind direction. Operators should be aware of the effects of even small lateral wind components on the displacement and alteration of deposit pattern. Flight with a crosswind component to the flight line produces a distorting effect on the aircraft wake and spray pattern. The effect on the wake is shown by considering the applications shown in Figure I-1t. Application A was made in a 8.6 mph (4.3 m/sec) wind at 4 degrees from the right of the flight line. Application B was made with a 7.2 mph (3.6 m/sec) crosswind at 23 degrees to the right of the flight line. Application parameters were identical in both cases with the aircraft passing over the 200-foot distance marker. Not only is the pattern altered in shape, being spread downwind with lower peak deposits, but it is displaced approximately 50 feet downwind. These subtle changes in spray conditions can have pronounced effects on the ability to overlap swaths accurately and to successfully apply complete spray to the canopy.

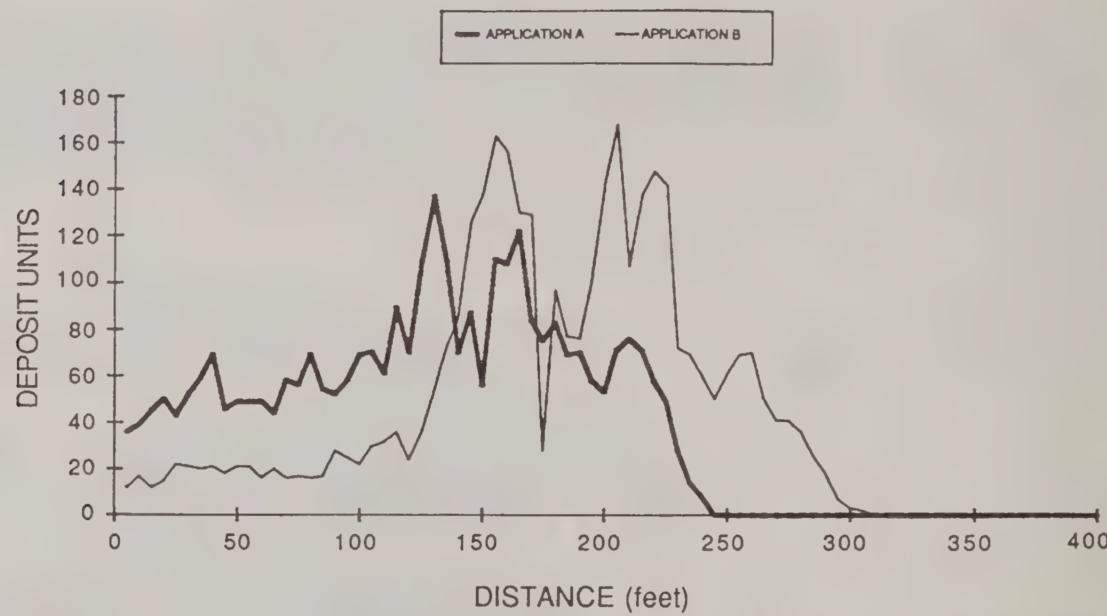

Figure I-1t. Effect of a crosswind component on the position of the spray pattern. Application B was made in a 8.6 mph (4.3 m/sec) wind 4 degrees from the right of the flight line. Application A was made with a 7.2 mph (3.3 m/sec) crosswind at just 23 degrees to the right of the flight line. Note how application A is displaced approximately 50 feet downwind, almost one full lane separation.

Example 2: flight crosswind; VMD 250 mm. Flight with the aircraft at right angles to the wind direction produces a distorting effect on the aircraft wake and spray pattern (Fig. I-1u) plus the displacement mentioned above. The resultant pattern has an extended downwind tail, consisting of the smaller droplet fraction of the spray (Fig. I-1v).

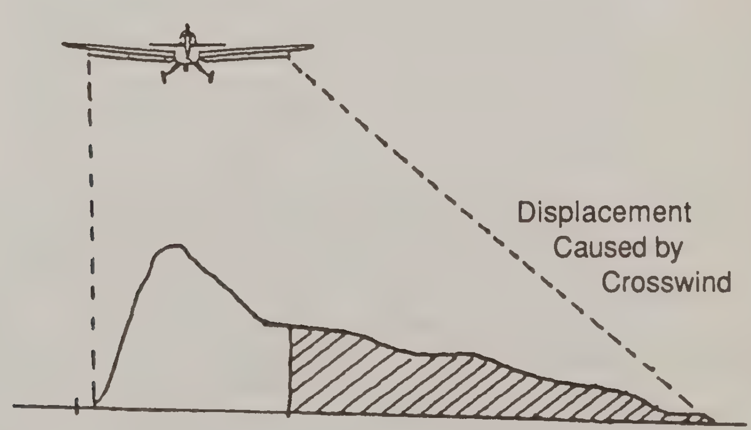

Figure I-1u. Distribution of spray from a flight line with a crosswind. Note the downwind displacement of the spray pattern and the lack of extended pattern on the upwind side of the spray pattern.

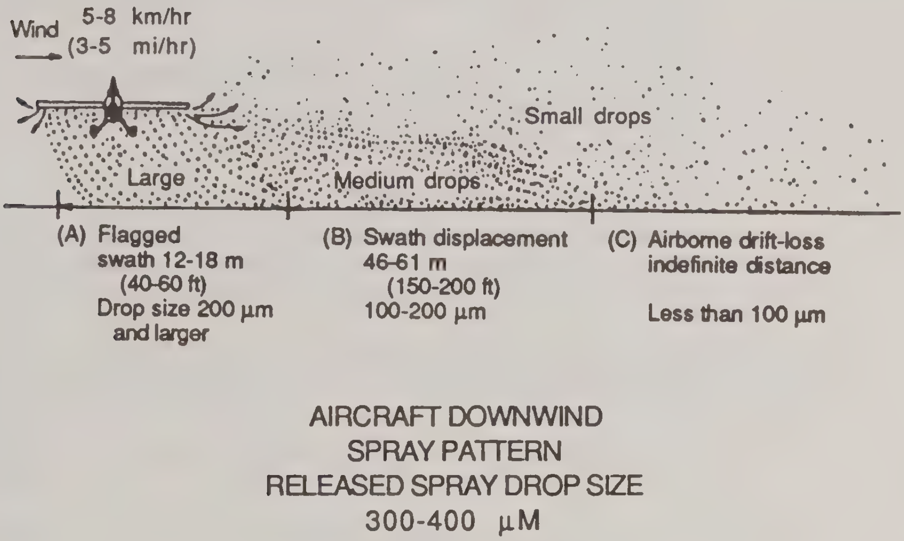

Figure I-1v. Downwind dispersal of different droplet sizes. (Source: Akesson and Yates 1984).

Characterization of a swath width from this method of flight may clearly give the impression of a large useable lane separation. However, two potential problems need to be considered. The extended swath is a product of the crosswind. During characterization, it may be possible to orient the collection lines and flight line across a clear airfield to maximize the swath width. However, the pattern will not be even across the swath. Although material may arrive quite a distance from the aircraft, it will be at considerably below effective dosage rate. In practice, actual application conditions are unlikely to be so amenable. If the weather conditions prevailing at the time of application do not present the same crosswind strength as the winds at characterization, then, the swath actually achieved at application will fall short of that expected.

The ability to fly with a crosswind that produces an extended swath relies on the opportunity to fly a block according to wind direction. Many times a block's orientation and shape, or topography, only permit efficient application in one direction. If this direction does not happen to coincide with the crosswind method, then, the swath width will again be over-extended for the actual conditions.

Probably the most common application method is flight with some degree of crosswind but using a lane separation determined by characterization into the wind. This method will be less susceptible to large differences in swath placement (see Fig. I-1t), since a degree of displacement will always be present, and will not run the risk of using extended swath widths derived from characterization done under crosswind conditions. In addition, the overlapping tendency of adjacent swaths will serve to limit the amount of untreated area.

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2. IMPORTANCE OF WEATHER IN AERIAL SPRAYING

Robert Sanderson

Introduction

The aerial application of pesticides is greatly affected by temperature, wind, and relative humidity in the general spray area. These factors are especially important in the microclimate area, which is usually defined as the first 40 feet of the atmosphere. A spray cloud may be carried aloft, or downwind, away from the target area. This results in significant amounts of pesticide being wasted and/or subject to drift, with potentially serious legal liability for the applicator and others associated with the spray program. Familiarization with some of the important meteorological principles that reduce the risk of drift and enhance spray deposition could be very useful to the applicator and others involved in aerial spray programs.

There are three main weather stages important in a spray program: 1) Pre-spray weather - the main effect of the weather before application is the crop condition. Take-up and retention of spray material can be affected by frost, heavy dew, or rain. Frost on the aircraft can also delay flying. 2) Application weather--the deposition and dispersal of spray is affected by wind direction, speed, and turbulence. Evaporation is affected by temperature and humidity. 3) Post-spraying weather--rain can cause material to be washed off the treated surfaces.

Major Meteorological Parameters

Wind. Differences in barometric pressure over the earth's surface are the primary causes of winds. At great distances above the earth's surface, air movement is determined simply by these pressure forces and by forces due to the earth's rotation. Below about 2,000 feet, the surface friction retards the movement of air and generates fluctuations; i.e., turbulence. This lower region is known as the planetary boundary layer. A typical weather map (Fig. I-2a) shows areas of high and low pressure separated by isobars (one line of equal pressure). If the isobars are close together, the pressure gradient is large and the winds are strong. When there are only slight variations in barometric pressure, the wind is light and tends to be variable--a very important factor to consider in aerial spray operations.

When weather is under the influence of high pressure (a "high"), skies are generally fair, but when low pressure (a "low") moves in, the weather usually turns stormy.

In the Northern Hemisphere, air moving outward from a high flows in a clockwise spiral, and air moving toward a low flows in a counterclockwise spiral. The prevailing high-altitude wind direction will tend to be parallel to the isobars, but wind direction has a systematic change with height. In the Northern Hemisphere, this change is clockwise with increase of height from the surface. This is known as the Ekman spiral. As a rough guide, the wind direction will change 20-40 degrees between the ground and 2,000 feet altitude. Thus, if the isobars indicate a wind from the North, this would change to a Northwest wind close to the ground. Wind direction can also be affected by local factors such as thunderstorms and topography.

Wind speed. Meteorological measures and reports of wind usually relate to a reference height of 33 feet (10 meters) above the ground, but wind speed actually varies with height. When a mass of air moves, the frictional drag of the underlying surface slows down the air and results in a wind profile in which the mean wind speed increases with height up to about 2,000 feet. The increase is approximately logarithmic and depends on the physical roughness of the surface (see Fig. I-2b).

Turbulence. The shearing stress associated with the increase in wind speed with height produces frictionally driven eddies in the air flow. Wind profiles and eddies can be simply visualized as shown in Figure I-2b. The average size of turbulent eddies increases with increasing height and depends on surface roughness. When the surface roughness is low (grass), eddies are small; however, when the roughness is high (forest), the eddies are large. This turbulence, known as "frictional turbulence," is produced solely by the wind action and is separate from "convective turbulence" produced by buoyancy effects due to temperature.

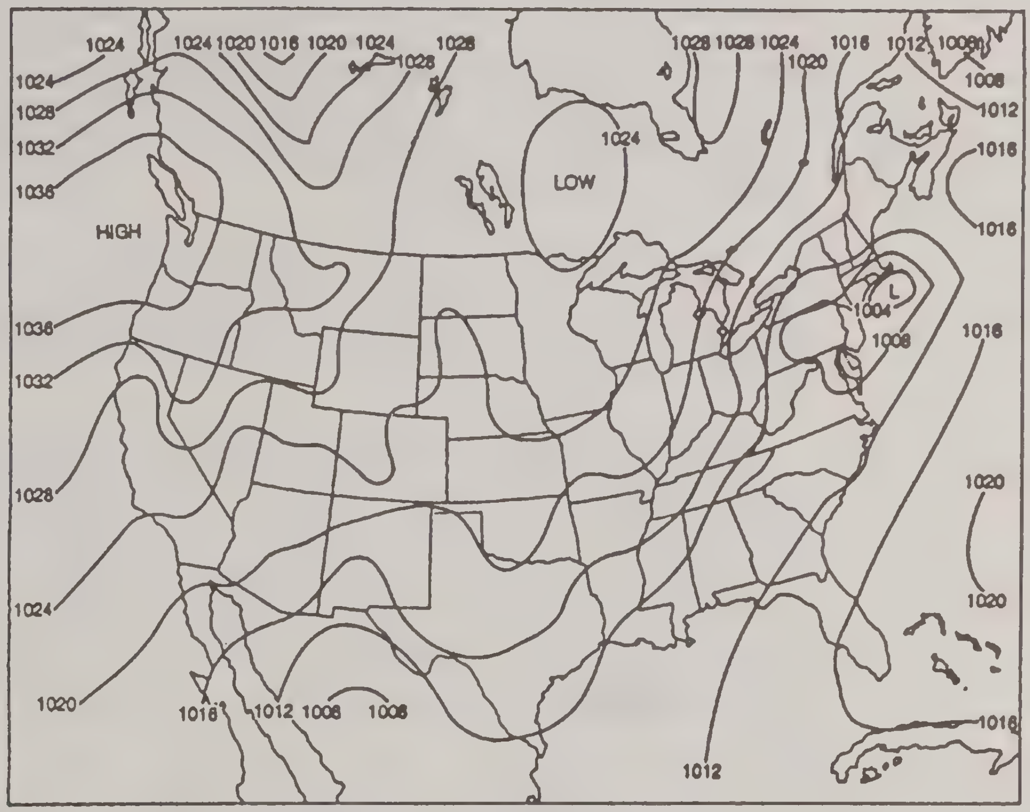

Figure I-2a. Typical synoptic weather map. Isobars in millibars show lines of equal atmospheric pressure. (Source: National Oceanic and Atmospheric Administration)

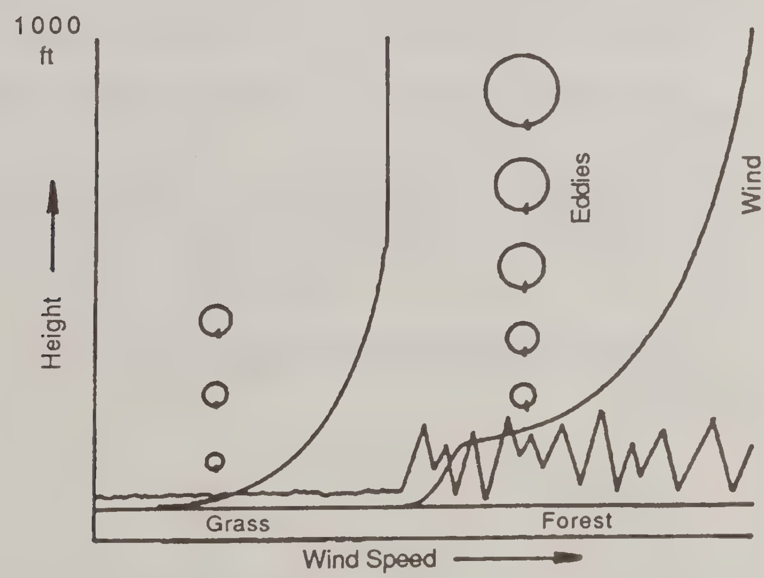

Figure I-2b. Turbulent eddy formation during air movement over smooth and rough surfaces. The size of the eddies increases as the surface roughness increases. Note that over both smooth and rough surfaces, the size of the eddies increases with height.

Temperature and air stability. In strong winds, the frictional turbulence produces mechanical stirring of the air, which promotes strong mixing in the atmosphere and tends to destroy homogeneities of temperature. In lighter winds, especially where there is intense radiation, temperature can vary significantly with height. Temperature variations are caused by solar radiation and heat exchange between air, soil, and vegetation. The change in temperature with height is called the vertical temperature gradient. The temperature gradient has an important effect on atmospheric stability because it can increase or decrease air mixing.

If a parcel of air were suddenly lifted up, the parcel would expand because air pressure decreases with height in the atmosphere. In expanding, the parcel expends energy in the form of heat; hence, the parcel's temperature drops. A parcel of dry air normally cools at a rate of about 5.5°F per 1,000 feet increase in height. This is known as the dry adiabatic lapse rate.

If the temperature decrease with height is greater than the adiabatic rate so that surrounding air temperature at every elevation is lower than the temperature of the air parcel rising through it, then, the parcel will continue to rise like a hot air balloon. In such a situation, the surrounding air layer is said to be unstable because once a parcel of air is disturbed, it tends to continue its movement. If, on the other hand, the temperature change is less than the adiabatic rate, the parcel enters a layer of air whose temperature at every elevation is warmer than the parcel, the parcel is no longer buoyant, and it begins to sink. In this case, the air layer is said to be stable because once a parcel of air is disturbed, its continued movement is restricted. If the parcel enters a layer of air whose temperature is the same as that of the parcel, then, it neither rises nor sinks, and the air layer is said to be neutral.

Under certain conditions, temperature can increase with height; this condition is extremely stable and known as an inversion. This can only occur over a limited height range, since there must be an overall drop in temperature with increase in height because of the decreasing pressure. Inversions usually occur when the wind is zero or very slight and may develop by the 'sinking' of cold dense air pushed in by weather fronts or by radiational cooling of the surface, especially on clear nights. Inversions are important in spraying operations because small droplets rely on turbulence to bring them to earth. In a strongly stable atmosphere like an inversion, this turbulence is very restricted. Thus, small droplets are more prone to drift from a target site under inversion conditions.

If the temperature remains constant with height, then, the condition is known as isothermal. The different temperature gradients are illustrated in Figure I-2c.

Frictional turbulence is enhanced by unstable conditions and air mixing increases. Stable and inversion conditions dampen frictional turbulence and reduce mixing. In a dense forest canopy, the temperature gradient can be different at different heights, and it will normally change in a cyclic pattern during the day as shown in Figure I-2d.

Atmospheric stability and stability ratio. The stability ratio (SR) is a useful index of atmospheric stability. It includes effects of both wind speed and temperature and is defined by:

$$SR = \frac{T1 - T2}{U^2} \times 59.8$$

where: T1 is temperature at height 33 ft (10 m)
T2 is temperature at height 8 ft (2.5 m)
U is mean wind speed in ft/sec at 16.5 ft (5 m)

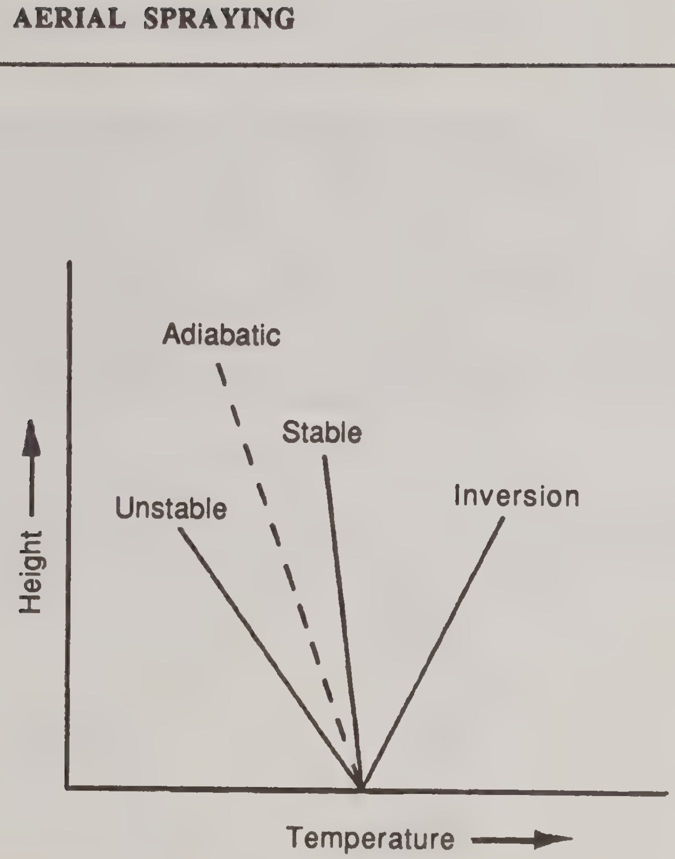

Figure I-2c. Atmospheric Stability. The graph shows changes of ambient air temperature with height in cases of air of different stability. The profile determines whether air which is warmed by the sun and made to rise will go on rising, whether it will rise to a certain height and stop moving, or whether it will sink down again. These factors are very important in determining good spray conditions.

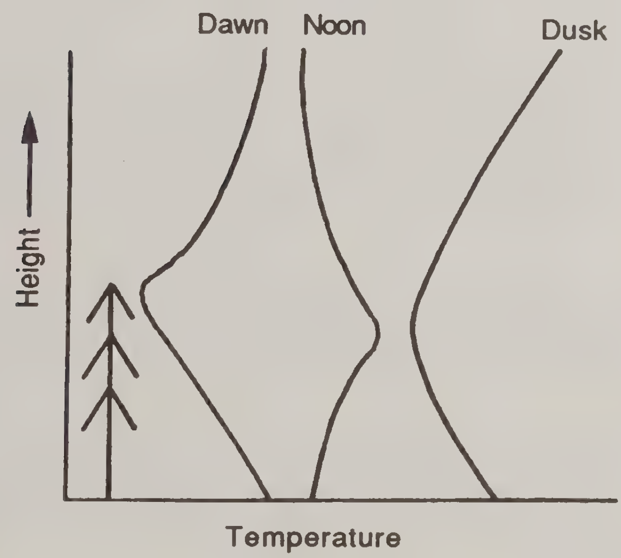

Figure I-2d. Temperature profiles with height in a forest canopy at different times of day. At dawn, the air beneath a canopy is moderately unstable while the air above is stable. This situation reverses during a sunny day and returns towards the dawn pattern at dusk.

The stability ratio becomes increasingly negative when the temperature at T2 is higher than at T1, indicating unstable or turbulent conditions. A large positive value indicates stable conditions. When the SR is near zero to slightly negative, this indicates that mild mixing conditions exist. As an example, the evaluations of micrometeorological conditions have shown the relationship of atmospheric stability as related to trends in drift residues (Table I-2a). The higher wind velocities usually produce near neutral stability and thus reduce the residue concentrations by spreading the aloft spray mixture over a greater distance. Conditions of unstable air with much turbulence mean spray is brought to earth quickly, and downwind residue is reduced. Very stable or inversion conditions allow greatest downwind transport.

Table I-2a. Relationship between atmospheric stability ratio (SR) and residues captured downwind

Atmospheric condition	SR	Amount of residue captured downwind
Unstable	-1.7 to 0.1	lowest
Neutral	-0.1 to 0.1	
Stable	0.1 to 1.2	
Very stable	1.2 to 4.9	greatest

Relative humidity. Relative humidity, temperature, and the concentration of nonvolatile substances affect the evaporation rate and final size of spray drops. Even relatively large drops will be significantly reduced in size on hot, dry days. A droplet 170 µm in diameter falling near 20 feet (6 meters) and taking about 14 seconds with a 68 percent relative humidity and 88°F would be trimmed down to near 120 µm. Drops less than 100 µm in diameter are considered very susceptible to drift and may pose a serious hazard. Of course, rates of evaporation and the final size of the droplet are affected by the concentration of the degree of nonvolatile substances in the spray mixture.

Effect of Weather on Spray Deposition

Wind influences the movement of spray droplets both by carrying drops away from the target area and, through the action of turbulence, by modifying their fallspeed relative to the ground. The effect of turbulence will be negligible for large drops, therefore, movement will be dominated by sedimentation. With small drops, sedimentation can be neglected, and droplet movement will be governed by an instantaneous airflow. These drops require turbulence to bring them down into the canopy.

It is difficult to define suitable spraying conditions because the decision will be influenced by crop, pest, and location. Strong winds increase the collection of small droplets by vertical stems and needles, but they also carry droplets large distances, which could result in extensive swath displacement or downwind fallout.

In extremely stable conditions, mixing is suppressed, and small droplets can drift over great distances. The dispersal of the cloud is minimal, so, when the cloud does reach the ground, the deposit could be high and might cause contamination in susceptible areas. In extremely unstable conditions, small droplets can be carried high by thermal turbulence and become a drift hazard.

If conditions are favorable for inversion layers to form, it is important to know where the layers change. The extremely low turbulence associated with an inversion layer causes small particles released above the inversion layer to spread out rather than penetrate it.

As a guide, it is important in aerial spraying operations not to spray when winds exceed 10 mph, extremely stable conditions, high temperature (above 80°F), and low relative humidity (less than 50 percent).

Daily Weather Changes

Wind and temperature vary throughout the day. Winds are usually low during the night, and a temperature inversion can occur as the ground cools. The air near the ground will cool more quickly than at high elevations, giving an increase in temperature with height, hence, an inversion. Inversions diminish after dawn as the ground or canopy warms up by solar radiation. Winds increase until late afternoon when they begin to decrease as a consequence of increased atmospheric stability caused by cooling of the land mass.

In mountainous areas, drainage winds, due to differential heating of hillside and valley air, cause a daily pattern of air movement. Before sunrise, there are downslope winds and generally a temperature inversion; after sunrise, the downslope winds diminish, the inversion lowers, and the temperature rises. About 1 hour later, upslope winds begin.

3. AERIAL SPRAY NOZZLE TYPES AND FUNCTION

Robert Sanderson

Introduction

A nozzle is any device through which liquid is emitted, broken up into droplets, and dispersed. The main types of nozzles are: hydraulic, which uses pressure to atomize; gaseous, which uses shear between two fluids; rotary, which uses centrifugal force: and electrostatic, which uses electrical energy. Hydraulic and rotary nozzles are the types commonly used in aerial spraying operations and are the ones discussed here.

Hydraulic Nozzles

Droplet production. Droplets are produced when liquid under pressure is forced through a small opening or orifice so that there is sufficient velocity for it to spread out as a thin sheet. Sheet development is influenced by pressure, surface tension, viscosity, density, and air temperature. A minimum pressure is required for sheet formation. Flow rate increases in proportion to the square root of the pressure; so, doubling the spray pressure increases flow by about 40 percent. Changing the pressure then has a limited effect on the flow rate. Adjustments in flow rate are best achieved by changing the number or size of nozzles.

Mechanism of sheet disintegration. Sheet disintegration (Fig. I-3a) can be described in three phases:

- Rim--Surface tension contracts the edges of the sheet into ligaments that break up into droplets
- Perforations--Holes develop in the sheet, boundaries form unstable ligaments that break up into droplets
- Wavy sheet--Instability in the sheet causes whole sections of the sheet to be thrown off and broken into droplets

Figure I-3a. Mechanisms of sheet disintegration during droplet formation in hydraulic nozzles.

Sheet disintegration is irregular and produces a wide range of droplet sizes (10-1,000 µm). Viscosity and surface tension resist sheet formation and breakup, hence, droplet size increases with an increase in viscosity or surface tension. Viscosity should be less than 16 centistokes for adequate "fan" and droplet formation. Increasing pressure usually reduces droplet size because more energy is being applied, but, since pressure also increases flow rate, the relationship should be determined for a particular nozzle. The normal operating pressure range is 25-60 psi.

Components of hydraulic nozzles (Fig. I-3b). The body of the nozzle can be of various types--brass, plastic, or stainless steel. It holds the tip and connects it to the boom. The check valve is a spring and diaphragm anti-drip device. The filter prevents blockage of the nozzle tip. A 50-mesh filter is usually adequate except for a very small tip orifice when an 80, 100, or 200 mesh may be needed. Recommended mesh for each nozzle size is given in the manufacturer's catalog.

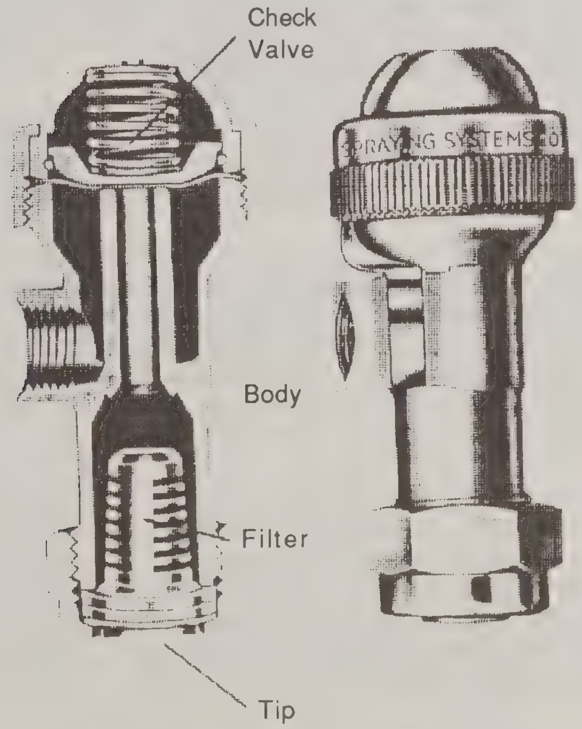

Figure I-3b. Components of a hydraulic nozzle. The example illustrated shows a flat fan nozzle fitted with a slotted screen (filter), as would be used for spraying wettable powders. The check valve exerts a pressure on the liquid of approximaetly 5 psi, and causes a rapid positive shutoff after the pilot stops spraying.

Types of tips. With the impact tip, a jet of liquid impinges at high velocity on a smooth surface. Droplets produced are large. This tip is widely used for herbicide application to reduce drift. The fan tip produces two jets of liquid that strike each other at an angle greater than 90°, producing a thin sheet in the shape of a fan. The shape of the sheet is determined by the shape of the orifice. A range of droplet sizes and flow rates is obtained by different orifice sizes. With the cone tip, liquid is forced through a swirl

plate into a chamber. An air core is formed as the liquid passes with high rotational velocity from the chamber through a circular orifice. The thin sheet of liquid emerging from the orifice forms a hollow cone. A solid cone pattern can be achieved by passing liquid through the nozzle to fill the air core. This generally gives a narrower spray angle and larger droplets. A range of flow rates and droplet sizes can be obtained by combination of swirl plates and orifice sizes.

Spray tip designation. Nozzle tip manufacturers usually have an identification system. Fan tips are designated by the fan angle and the flow rate at a pressure of 40 psi. For example, a Spraying Systems Tee Jet 8002 is an 80-degree fan angle and flow rate of 0.2 gal/minute. The same size Delavan nozzle would be LF-2 80.

Cone tips are designated by the orifice size in 1/64ths of an inch and the core number. For example, Spraying System Tee Jet D8-46 is an 8/64th orifice disc and a 46 swirl plate or core size. Equivalent Delavan tip would be DC 8-46.

As nozzles are used, abrasion and erosion will increase the orifice size and alter the flow rate. Nozzles should be frequently checked for calibration and discarded if the flow rate has increased by greater than 10 percent. Nozzles should definitely be checked for calibration before the initiation of a project.

In aerial application, the droplet size produced by a hydraulic nozzle is influenced by the air shear caused by the slipstream. Increased flying speed or orientation of nozzles into the air stream will decrease the droplet size (Fig. I-3c).

Rotary Nozzles

There are three modes of droplet formation from a rotary nozzle (Fig. I-3d): the direct drop formation, in which individual droplets leave the edge of the nozzle; the ligament formation, in which the liquid leaves the edge of the nozzle in curved threads or ligaments that break down into droplets; and the sheet formation, in which, if the nozzle is flooded, a sheet leaves the edge of the nozzle and disintegrates into droplets in the same way as sheets from a hydraulic nozzle.

Examples of rotary nozzles are the Micronair, the Beecomist, the Mini-Spin, and the Acu-mist. Probably the most common rotary nozzle is the Micronair, (Fig. I-3e). The nozzle consists of a cylindrical metal wire gauze rotating around a fixed hollow spindle. Speed of rotation is controlled by adjustment of the pitch and/or the shape of propeller blades (Fig. I-3f). To adjust the blade angle, bolts are slackened on the clamping ring and the blades twisted to the required angle, aligning the mark on the blade with the desired setting on the clamp ring.

Increasing the blade angle setting slows the speed of rotation and increases droplet size (Fig. I-3g). Spray liquid is pumped to the hollow spindle via a variable restrictor unit (VRU). The VRU consists of a fixed plate with a series of seven differently sized holes around its edge. Changes in the flow rate are achieved by changing the hole size in the restrictor plate. It is important in using this atomizer to make sure the VRU spring is in good condition to ensure that the plates are kept together. A deflector plate distributes liquid to the front and rear of the nozzle. The liquid is then coarsely atomized by being passed through a diffuser tube and then fully atomized by centrifugal force as it strikes the rotating gauze cylinder. Blockages are rare with these nozzles, since small orifices are not required.

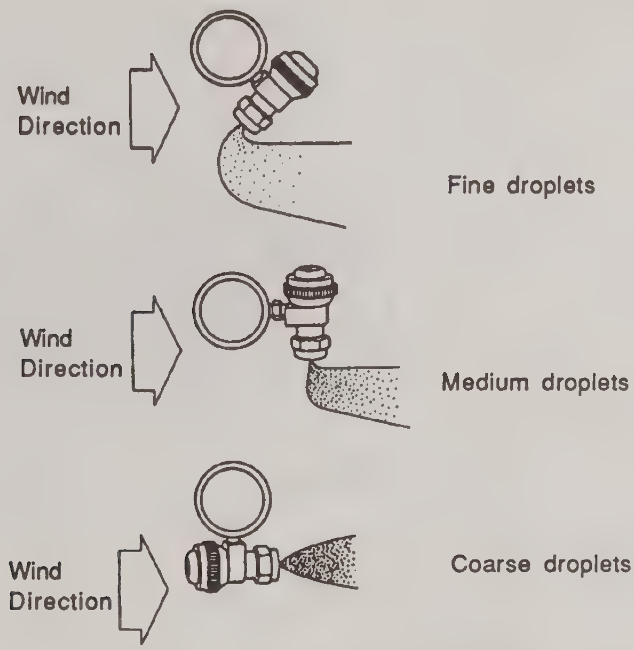

Figure I-3c. Droplet shear caused by the variation of nozzle position. The relative angle between the nozzle and the relative airflow is used to control droplet size. The smallest sizes are caused when the droplets are released against the airflow. In contrast, the largest droplets are obtained when droplets are released with the airflow.

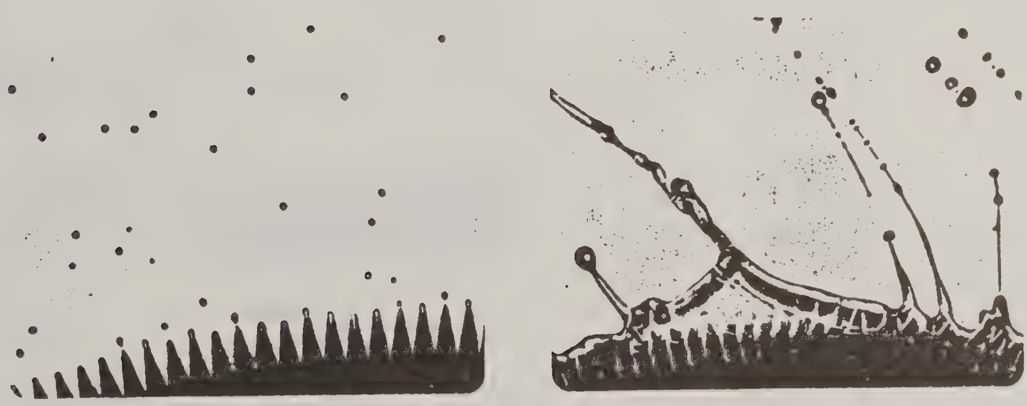

Figure I-3d. Photomicrographs of droplets being emitted from a spinning disc atomizer. The droplets are very uniform in size at low flowrates until the disc is overloaded, when sheet breakup rather than ligament breakup occurs. (Source: Micron Sprayers, Ltd.)

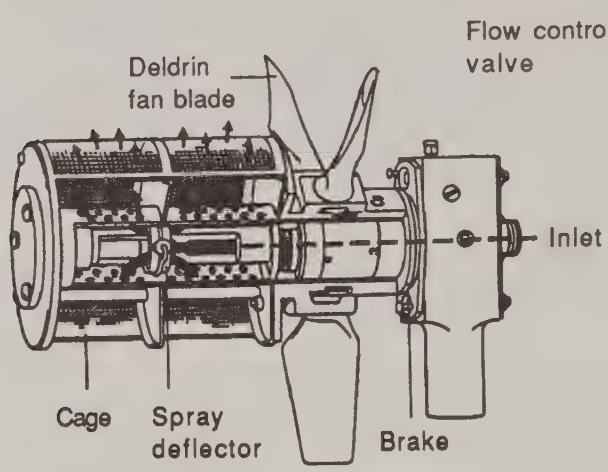

Figure I-3e. Micronair AU3000.

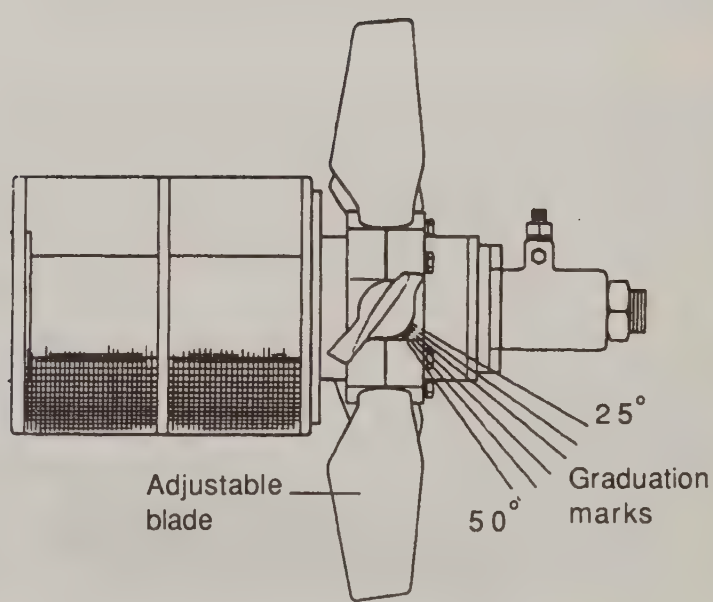

Figure I-3f. Details of blade angle on a Micronair AU3000. Graduation marks in steps of 5° are inscribed on the ring in earlier models (shown). These markings have been superseded by a system where marks on the blades are adjusted to line up with the dividing line in the fan clamping ring.

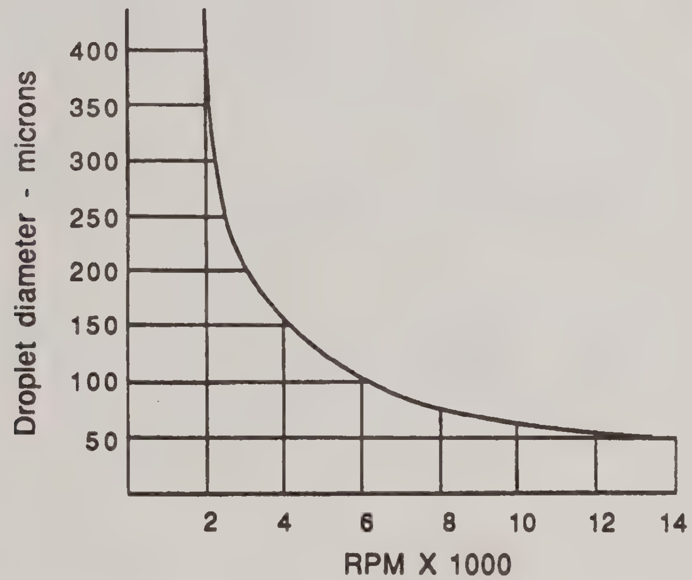

Figure I-3g. Effect of rotational speed of the Micronair range of atomizers on droplet size (Source: Micronair AU3000 product literature, Micronair FL 33166)

CHAPTER II.

AIRCRAFT CALIBRATION AND CHARACTERIZATION AND SPRAY PATTERN ASSESSMENT

1. Aircraft Calibration

Karl Mierzejewski

Introduction

The objective of calibration is to set up the aircraft so that it can deliver the correct volume of insecticide per minute through its application system under normal operating conditions. Such calibration is vital for effective spraying. Unless the precise flow rate of the spray system is known, it is not possible to apply the required dose rate of insecticide.

Calibration is performed by setting up the application equipment to conform to previously calculated specifications and adjusting it as necessary through testing in the field. Many of the variable parameters will have already been determined by the contractor in the aircraft's configuration. However, there will still be many adjustments that can be made. In gypsy moth control, the two main pesticides used, Dimilin and Bt, are made up as liquid emulsions or suspensions with several parts of water. This means that the characteristics of the sprays do not differ markedly from water and enables initial calibrations to be undertaken using water. When Dimilin is used, any subsequent minor recalibrations that will be necessary because of differences between water and the pesticide can be done in the course of the first few operational runs. With some of the more viscous Bt formulations, however, the final calibration should be made with the actual spray material. This is especially true if undiluted Bt is going to be used.

This section describes how to calibrate aircraft with different equipment so that it can conform to the requirements of the spray contract. This means that the output of the aircraft (in terms of gallons per minute) and its productivity (in terms of acres per minute) must be coordinated.

The Basics

How do I calibrate?

- Establish the work rate of the aircraft in acres/min. For this, one must obtain the recommended lane separation and application speed for the type of aircraft.
- Ensure that the correct atomizers are fitted to produce the required droplet spectrum.
- Adjust flow rate through the application system so that the correct application rate is obtained for the chosen work rate.

What can I change on the aircraft or the application equipment?

Boom and nozzle spray equipment:

- Nozzle type can be changed.
- The number of nozzles on the boom can be increased or decreased.
- Repositioning of nozzles is usually possible.

Rotary atomizer spray equipment:

- Flow rate to the unit can easily be adjusted.
- The droplet spectrum can be varied from coarse to fine as required.
- The positioning of the unit on the aircraft can often be changed.

Preliminary Calculations

Before doing any empirical evaluation, it is necessary to spend some time with a calculator to determine what is required.

Step 1. Determine the work rate of the aircraft in terms of acres per minute.

(a) Obtain the lane separation for the particular type of aircraft you are working with from Chapter II-3.

(b) Obtain the application speed from the applicator. (Remember, mph = knots x 1.16).

(c) Apply Formula 1 to establish the work rate.

Formula 1

$$\text{Work Rate} = \frac{\text{Lane Separation} \times \text{Application Speed}}{495}$$

Units: Work Rate = acres/minute
Lane Separation = feet
Application Speed = mph

Step 2. Calculate the gallons that must be sprayed per minute (the flow rate) to apply the recommended application rate using Formula 2. Note that the term dose rate refers to amount of active material applied per unit area, whereas, application rate (or volume rate) refers to volume of spray applied per unit area. In some texts, you may see the term emission rate. This is the same as the flow rate (used here) and refers to the volume of spray being applied per minute.

Formula 2
Flow Rate = Application Rate x Work Rate

Units: Flow Rate = gallons/minute
Application Rate = gallons/acre
Work Rate = acres/minute

Step 3. Select a nozzle (boom and nozzle equipment). (Note: If you are using rotary atomizers, refer to Step 3(a), rotary atomizers.) Count the number of nozzles that are fitted on the boom. Also count the number of positions there are for nozzles. This represents the maximum number that can be mounted directly on the boom (although in some areas the total number can be increased by the use of T-joints on the boom mounting positions).

It is most important that the nozzle locations on the boom do not exceed three quarters of the wingspan. Nozzles situated toward the wingtips spray into the large swirling vortices that come off both wings and could result in the off-target drift of spray. Therefore, if the only way of accommodating the required flow rate is by extending the location of nozzles right to the wingtips, the nozzle type should be changed to one with a higher flow rate and the three-quarter wingspan rule adhered to.

The number of nozzles fitted can vary from the maximum that can be located on the boom (usually about 60 nozzles in single-engine agricultural-plane) to about half that number.

Apply Formula 3 to calculate the flow rate per nozzle:

Formula 3
$$\text{Flow rate per nozzle} = \frac{\text{Flow rate required (see Formula 2)}}{\text{number of nozzles}}$$

Refer to Figure II-1a and 1b or the manufacturer's catalog to select the nozzle that most nearly matches the calculated nozzle flow rate. The required flow rate should fall in the middle of the box in the figure, so that the flow rate can be increased or decreased by spray boom pressure adjustment.

The nozzles usually used in gypsy moth control are either 80° flat spray or hollow cone (disc-core) nozzles. Table II-1e lists the equivalents of these two types of nozzles for the two main suppliers, Spraying Systems and Delevan. These nozzles will produce droplet spectra suitable for correct deposition in forest canopies. Although it is possible to fit a small number of large nozzles that will provide the correct flow rate in terms of gallons per minute, such nozzles will not provide effective atomization of the pesticide, resulting in a small number of large droplets. If the type of nozzle fitted to the aircraft is not covered in this manual, ask the aerial applicator for manufacturer's literature.

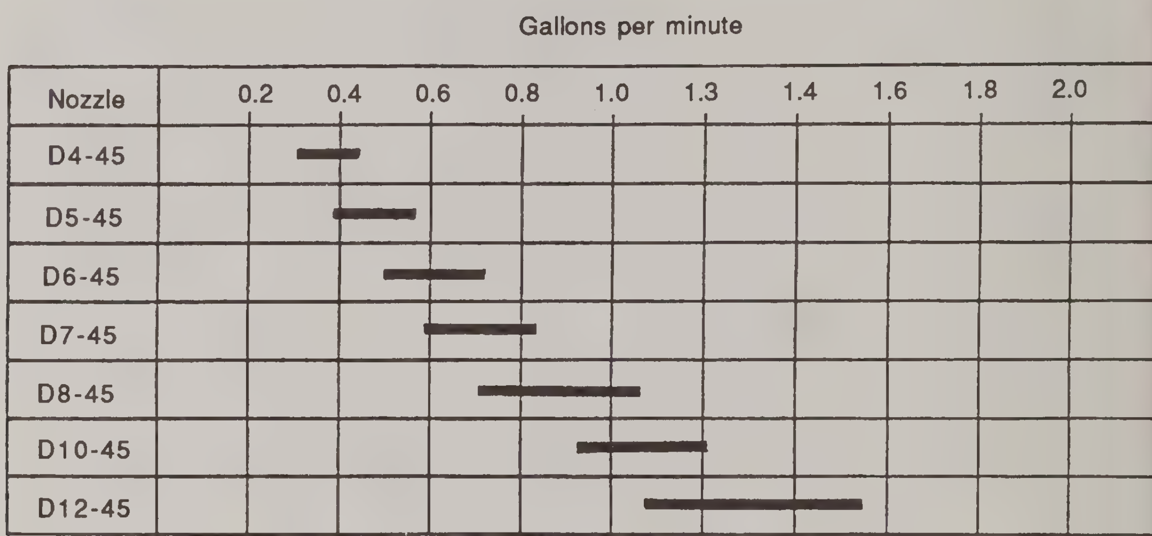

Figure II-1a. Spraying Systems Hollow Cone/No. 45 Core (30-60 psi). Bars show the flow rate per nozzle (in gallons per minute) for Spraying Systems Disc-Core TeeJet (Hollow Cone nozzles) between 30 and 60 psi. All nozzles in this figure are fitted with a No. 45 Disc Core. "D" numbers refer to the size of the orifice disk opening in 1/64 inch.

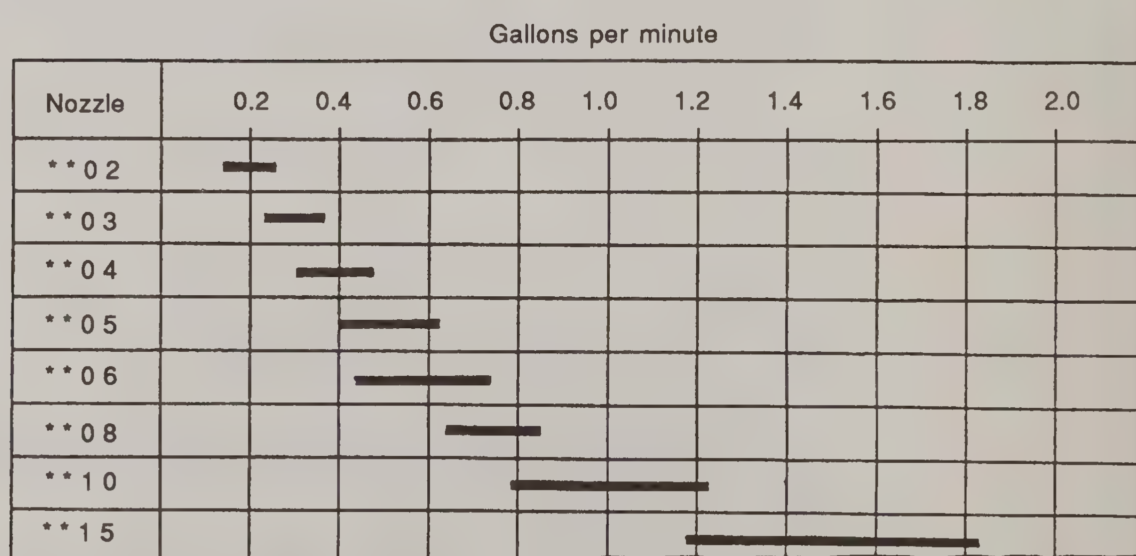

Figure II-1b. Spraying Systems Flat Spray Nozzles (65°, 80°, and 110°). Bars show the flow rate per nozzle (in gallons per minute) for Spraying Systems TeeJet Flat Spray Nozzles (Flat Fan nozzles) between 25 and 60 psi. In the Spraying System numbering method, the angle of the spray is used for the first two (or three) digits, and the flow rate (in gallons per minute x 10) at 40 psi and used for the last two digits.

Nozzle flow rate varies with the square root of the boom pressure. Therefore, doubling the boom pressure would increase the flow rate by about 40 percent. Varying the boom pressure between 25 and 60 psi (the normal range for aerial spraying) produces a flow rate difference of 55 percent. This difference can be used for fine adjustment of the flow rate once the nozzle type has been chosen. However, it should only be used for such small adjustments. A high boom pressure will overstress the system and produce large numbers of the driftable droplets, whereas, too low a pressure (less than 25 psi) will result in too coarse drops being produced.

Step 3a. To adjust flow rate (rotary atomizers), for Micronair atomizers: Apply Formula 3 to determine the required flow rate per atomizer. The flow rate is controlled by a variable restrictor unit (VRU). Choose the VRU and pressure combination from Tables II-1a - II-1d, which give the closest flow rate to that required. Note that all VRUs should be at the same setting in order to maintain an even swath pattern.

For Beecomist atomizers: Apply Formula 3 to determine the required flow rate per atomizer. In most configurations, the pesticide input into the unit is controlled by a Spraying Systems Tee Jet nozzle body with interchangeable orifice disc. Refer to Table II-1d (flow rates for different orifices at 30 psi) to select the most suitable disc. Use Formula 4 (see below) to calculate flow rate for different pressures.

Remember that manufacturers' nozzle and rotary atomizer calibration data are usually based on experiments done with water and will be higher than empirically determined flow rates made with viscous pesticides.

The foregoing details the basic calculations that must be made prior to field testing. By this stage, the type of nozzle should have been determined as well as the number of nozzles and an estimate of the pressure required and the target flow rate per nozzle.

Table II-1a. Flow rates (in pints per minute) through AU3000 for different VRU settings and pressures. (Source: Micronair AU3000 Product Literature, Micronair FL)

VRU	Boom pressure (psi)					
Setting	25	30	35	40	45	50
1	0.26	0.33	0.45	0.58	0.74	0.90
2	0.38	0.43	0.54	0.65	0.92	1.20
3	0.61	0.76	1.05	1.34	1.72	2.10
4	0.87	1.08	1.50	1.92	2.46	3.00
5	1.22	1.51	2.10	2.69	3.45	4.20
6	1.74	2.16	3.00	3.84	4.92	6.00
7	2.52	3.08	4.19	5.30	6.85	8.40
8	3.16	3.90	5.38	6.85	8.83	10.80
9	4.51	5.60	7.79	9.98	12.79	15.60
10	5.92	7.35	10.21	13.06	16.53	20.00
11	8.34	10.37	14.44	18.50	23.75	29.00
12	13.50	16.50	22.50	28.50	36.75	45.00
13	14.88	18.50	25.75	33.00	42.50	52.00
14	24.19	30.05	41.78	53.50	68.75	84.00

Table II-1b. Flow rates (in pints per minute) through AU4000 for different VRU settings and pressures. (Source: Micronair AU4000 Product Literature, Micronair, FL)

VRU	Boom pressure (psi)					
Setting	25	30	35	40	45	50
1	0.58	0.72	1.00	1.27	1.39	1.50
2	1.22	1.27	1.38	1.48	1.69	1.90
3	2.48	2.64	2.96	3.28	3.57	3.85
4	2.24	2.64	3.44	4.23	4.47	4.71
5	4.76	4.99	5.46	5.92	6.45	6.97
6	4.79	5.20	6.03	6.85	7.12	7.39
7	7.55	7.81	8.34	8.87	9.51	10.14
8	7.50	8.03	9.09	10.14	10.92	11.70
9	10.35	10.90	12.00	13.10	14.26	15.42
10	11.35	12.04	13.42	14.79	16.17	17.54
11	16.06	16.90	18.59	20.28	21.76	23.24
12	20.49	21.55	23.67	25.78	28.21	30.64
13	32.54	34.23	37.61	40.99	43.21	45.43
14	32.86	35.08	39.52	43.95	47.13	50.30

Table II-1c. Flow rates (in pints per minute) through AU5000 + VRU for different VRU settings and pressures (Source: Micronair AU5000 Product Literature, Mincronair, FL)

VRU	Boom pressure (psi)					
Setting	20	25	30	35	40	45
1	0.61	0.90	1.18	1.32	1.45	1.52
2	0.95	1.10	1.25	1.47	1.69	1.80
3	1.63	1.82	2.01	2.25	2.49	2.61
4	2.64	3.33	4.01	4.45	4.88	5.10
5	3.97	4.68	5.39	5.97	6.55	6.84
6	4.71	6.25	7.78	8.71	9.63	10.09
7	5.41	6.81	8.20	9.14	10.08	10.55
8	6.57	7.54	8.51	9.51	10.51	11.01
9	8.24	9.93	11.62	13.06	14.49	15.21
10	8.81	10.49	12.17	13.40	14.63	15.25
11	13.65	15.54	17.43	19.76	22.08	23.24
12	15.91	17.74	19.57	22.32	25.06	26.43
13	18.38	20.98	23.58	27.43	31.27	33.19
14	19.86	25.75	31.63	36.02	40.40	42.59

Table II-1d. Flow rates (in pints per minute) through AU7000 for different VRU settings and pressures (Source: Micronair AU5000 Product Literature, Micronair, FL)

VRU	Boom pressure (psi)				
Setting	20	25	30	35	40
1	0.57	0.86	1.15	1.25	1.35
2	1.04	1.16	1.28	1.37	1.45
3	1.70	1.91	2.12	2.30	2.47
4	2.38	2.68	2.98	3.19	3.40
5	2.98	3.41	3.83	4.17	4.51
6	4.04	4.58	5.11	5.66	6.21
7	5.45	6.24	7.02	8.19	9.36
8	7.87	8.95	10.02	10.86	11.70
9	10.21	11.17	12.13	13.05	13.96
10	12.77	14.15	15.53	16.74	17.94
11	14.89	16.81	18.72	20.32	21.91
12	17.51	19.40	21.28	22.98	24.68
13	20.00	21.92	23.83	25.53	27.23

Table II-1e. Conversion factors between Spraying Systems and Delevan flat fan nozzles and disc-core nozzle tips.

Flat Fan--80° Angle

Delevan	Spraying Systems
LF 1.5	80015
LF 3	8003
LF 5	8005

Disc-Core Nozzle Tip Conversions

Delevan DC Disc-Core Nozzle	Delevan RD Raindrop Nozzle	Spraying Systems Disc-Core Nozzle
DC 2-13	--	D 2-13
DC 2-23	--	D 2-23
DC 3-23	--	D 3-23
DC 2-25	--	D 2-25
DC 3-25	--	D 3-35
DC 3-45	--	D 3-45
DC 5-25	RD 3	--
DC 5-45	RD 4	D 5-45
DC 7-25	--	D 7-25
DC 6-45	RD 5	D 6-45
DC 7-45	RD 6	D 7-45
DC 5-46	--	--
DC 8-45	RD 7	--
DC 12-45	--	D 12-25
DC 14-25	--	--
DC 6-46	RD 8	--
DC 12-45	RD 9	--
DC 7-56	RD10	D 7-56
DC 8-46	--	--
DC 8-56	--	D 8-56
DC 10-46	--	--

Tabulation for Orifice Discs

Flow rate for water at 30 psi (gallons per minute)

D1 = 0.10	D7 = 1.3
D1.5 = 0.14	D8 = 1.7
D2 = 0.18	D10 = 2.7
D3 = 0.24	D12 = 3.9
D4 = 0.43	D14 = 5.4
D5 = 0.67	D16 = 6.8
D6 = 0.98	

Source: Spraying Systems and Delevan Product Catalogs

Calibration

After the steps described above have been carried out and the aircraft set up according to the calculated configurations, it is necessary to field test the aircraft to ensure that practice conforms with theory. For example, nozzles may be worn, resulting in higher flow rates. Boom pressure may drop off toward the ends of the booms, causing lower than expected flow rates. Pressure gauges may give erroneous readings.

Aircraft pumps fall into two main categories: wind-driven or internally powered. Internally powered pumps are hydraulically or electrically driven and can usually be run at normal operating speeds on the ground. Therefore, calibration can take place on the ground. Wind-driven pumps get their motive power through a propeller that is driven by the relative wind produced by the forward movement of the aircraft. They may be calibrated on the ground, if the aircraft propeller can impart sufficient speed to the pump to enable it to produce the normal working pressure. However, it is more usual to fly aircraft when performing a calibration.

Standard Calibration Procedure

There are several ways to determine the flow rate of the aircraft application system. The method described in detail here is most commonly used.

Fill the aircraft hopper with water to a level that can be seen on the edge of the hopper or on the pilot's sight gauge in the cockpit. Forty gallons is normally adequate. It is now necessary to prime the spray system and the pump to eliminate air from the system and set the pressure. This can usually be done on the ground, even with wind-driven pumps. If not, a short flight will be necessary.

Park the aircraft on a level piece of ground. If the ground is uneven, mark the exact position of the wheels so that the aircraft can later be parked in the same position. Make a mark corresponding to the liquid level on the hopper.

Fly (or ground run) the aircraft so that the application system can be operated at its chosen operating pressure. The pilot must then run the system for exactly 1 minute (2 minutes if flow rates below 5 gallons per minute are being used).

When this has been done, park the aircraft in the original position and measure the amount of water needed to refill the hopper to the mark. The amount added represents the same volume used in the test spray. Do not forget to divide this amount by 2 if a 2-minute test spray was made or multiply by 2 if a 1/2 minute timing period was used.

Subtract the calculated amount from the measured amount of the test spray. Calculate the percentage difference:

$$\text{Percentage difference} = \frac{\text{measured rate-calculated rate x 100}}{\text{calculated rate}}$$

Positive percentages would mean excessive flow rates; negative percentages would mean deficits in flow rates.

Calculated value	Actions to be taken
± 5 percent	No adjustment necessary. Fine tune with pressure adjustment.
± 5-20 percent	(Small adjustment): Can usually be done by altering the boom pressure during application.
± 20-50 percent	(Moderate adjustment): Can be done by altering the number of nozzles and by boom pressure alteration.
>±50 percent	(Big adjustment): Alter nozzle type if you need to add or subtract nozzles.

(Note: In practice, the most convenient actions are taken. Thus, small adjustments may be made by adding or subtracting a few nozzles, instead of pressure alterations as described, if the applicator prefers.)

If using a viscous formulation of Bt, after checking with water, perform the final calibration run with the Bt tank mix that will be used in the application.

For other nonviscous pesticides, the flow rate will probably within $\pm$ 5 percent of that obtained with water. During the first application runs, ask the pilot to time the period needed for the hopper to empty. If the flow rate is slightly less than that measured with water, adjust the boom pressure accordingly in subsequent runs, using Formula 4.

Formula 4

$$\text{Required Pressure} = \frac{\text{measured pressure x (required flow rate)}^2}{(\text{measured flow rate})^2}$$

Deviation between calculated and measured flow rates. If the calculations have been performed correctly, the deviation between calculated and experimentally measured flow rates will rarely be more than 20 percent. If flow rate is found to vary from the calculated flow rate by a considerable margin, there could be several causes, acting singly or in combination. The reasons for too high a flow rate could be one of the following:

- The spray system has leaks.
- The pressure gauge is incorrect.
- The nozzles are worn.

System leaks. Make sure that all the diaphragm (or ball) check valves shut off when pressure is lowered to 5 psi. Verify that overflights over cards have not produced large droplet splashes. Such splashes would be indicative of leaks at boom joints, nozzle to boom joints, pump joints, or dump valve. Examine the spray as it comes out of the aircraft when it flies over. Look for a denser area in part of the spray just aft of the boom. Such an area may indicate leaks at boom joints. However, it is more likely that it would indicate use of nozzle bodies without tips or oversize nozzles.

Pressure gauge error. Has the pressure gauge on the spray boom been checked and calibrated recently? A faulty pressure-gauge reading will result in a flow rate error. A rule of thumb is that a false reading that varies by a certain value will give a flow rate that also varies by half that value. (Example: A 20 percent error in the gauge reading will give approximately a 10 percent error in flow rate.) A liquid filled pressure gauge is preferred.

Nozzle wear. Has the condition of the nozzle tips been checked recently? Nozzle tips should be replaced periodically because of wear. Nozzle life is difficult to predict. Some practical work has been performed by Spraying Systems. More is known about flat fan nozzles than about hollow cone because the tips are made of a single material. Hollow cone nozzles can have their swirl plates and orifices made up of different materials that can be combined separately, giving a large range of possible combinations. Several different factors influence this wear, including nozzle tip material, nozzle type, and the nature of the spray material.

Nozzle tips can be made of several materials that vary in their resistence to abrasion. In order of increasing resistance to wear, these are: brass/plastic/nylon, stainless steel, hardened stainless steel, and ceramic/sintered aluminum/tungsten carbide.

Flat fans are more prone to wear than hollow cone nozzles. In addition, if a hard, sharp object is used to unblock these nozzles, they can be easily damaged, resulting in increased flow rates.

Wettable powders cause rapid nozzle wear. Brass nozzles have been shown to increase their flow rates by up to 20 percent after spraying wettable powder formulations for only 18 hours.

Inadequate flow rate. Three main factors could result in a measured flow rate below that calculated: 1) Material more viscous than water was sprayed, 2) nozzle strainers or line strainers are blocked, and 3) the pressure gauge is incorrect.

The tables presented in this chapter are based on manufacturers' data that rely on the use of water as the spray liquid. In practice, the use of more viscous material such as Bt or wettable powder formulations results in a reduced flow rate. The viscosity error is the one most likely to affect the value of the field test, where it is known that the nozzles are in good condition.

If particulate products have been sprayed, this can often lead to blockages of strainer screens, especially if a fine mesh screen has been used. Nozzles near the end of the booms will be more likely to be blocked than inboard nozzles. Examine the spray as it comes out of the aircraft when it flies nearby. Look at spray from both individual nozzles and areas that appear lighter than the rest of the spray, 5 to 10 feet behind the boom. They will point to one or more blocked nozzles. If none of the nozzles (or rotary atomizers) are putting out the expected volume, suspect a blocked line strainer. Use of particulate fluorescent tracers with fine meshed nozzle screens can be a source of this problem.

Pressure gauge errors were discussed earlier in the section on flow rate deviation.

Alternative Calibration Methods

Some aircraft are fitted with flow meters that measure the flow rate through the spray system. These meters enable the pilot to make accurate adjustments to the flow rate in the air by adjusting the boom pressure. However, in such aircraft, the manual tank refill method should still be used as a final calibration check.

Instead of measuring the volume determined during a fixed time period, the time taken for a known volume to pass through the system can be measured. This method entails the priming of the spray lines (which typically hold about 5 gallons) by passing 10 or 15 gallons through the system until the system pressure indication begins to drop. The system is then shut off immediately, and a known quantity (usually the volume that has been calculated should be applied in 1 minute) is put into the hopper. The emission is accurately timed from switch-on to the fall in pressure and the flow rate calculated. In general, the results obtained by this method are more variable than those obtained with the refill method. In many aircraft, pressure gauges are mounted externally on the boom and are not easy to read, which can result in timing difficulties for the pilot.

Calibration of Micronair Rotary Atomizers

Micronair atomizers (AU 3000, AU 4000, and AU 5000) are adjusted separately for application rate and droplet size. Unlike the situation with hydraulic nozzles, these two variables are controllable separately. The main advantage of these atomizers is the ability to select the droplet size (VMD) of the spray for the required volume through quick adjustments. The quality of the spray (in terms of homogeneity of the droplet size) is similar to that of standard nozzles when used to spray volumes of 1 to 2 gallons/acre.

The flow rate is controlled by a Variable Restrictor Unit (VRU), which is fitted on each atomizer. Typically, a flow difference of a factor of 40 can be obtained between the smallest and the highest setting.

If the aircraft has a hydraulically or electrically powered pump, the Micronair ground calibration procedure described below should be adopted, otherwise, the standard calibration procedure should be used.

Ground procedure. The system should be primed and buckets placed under each unit (or under four of the units, positions 1, 3, 5, 7 left to right if eight units are fitted and labor is not available). The system should be run for 1 minute (or part of a minute), depending on the required flow rate. Measure the amounts sprayed. As with nozzles, adjustments can be made by varying the boom pressure, although the flow rate is more sensitive to variations in pressure than nozzles. Greater adjustments are made by changing the VRU setting.

Droplet size adjustment. Refer to Figure II-1d and II-1e (Droplet Size Charts) to select the speed required to produce the desired droplet VMD for the model of Micronair used. This curve should be used as a general guide. Micronairs come with a wide range of blade shapes and sizes. Figures II-1f-1h are graphs of the rotation speed of three models of Micronairs at different speeds and at three different flow rates for one blade type. (Refer to the manufacturer's documentation if the blade type used is not covered in these figures.)

A shallow blade adjustment (25°) produces fast atomizer speeds that give small droplets. Coarsening blade angle (up to 90° in the AU 4000) produces a droplet spectrum with progressively larger droplets. The blades can be adjusted by slackening off the bolts on the clamp ring. Micronair has changed its methods of adjusting the blade angles. Earlier models have the angles inscribed into the clamp ring aligned with a mark on the root of the blade. More recent blades have marks that are adjusted relative to the split line between the body of the atomizer and the clamp ring. New blades can be used with the old atomizers, as long as the inscribed angle markings are ignored. It is most important that all the blades in one unit be set at the same setting. However, it is possible to have the atomizers fitted at the wingtips set at a slightly coarser blade angle to generate larger droplets near the wingtip vortices. (Refer to the chapter on atomization for further advice.) Likewise, it may be necessary to set the blades on the left inboard wing to a slightly coarser setting. In this region, the air velocity is higher due to the presence of the prop wash. Consequently, a coarser blade setting will give the same rotational speed as that of other Micronairs further along the boom.

Example Calibration Problem

A contractor shows up with a spray aircraft that has been used for a contract where the application rate was 3 gallons/acre and is fitted with 40 Spraying Systems 8015 nozzles but has mounting positions for 50 in all. How is this aircraft to apply 1 gallon/acre of Dipel 8L, a Bt formulation?

The operator says that the spray system will usually work at pressures between 25 and 60 psi and that he flies at an application speed of 120 mph.

Step 1. Calculate the work rate from Formula 1.
Find out the lane separation that should be used for this aircraft from Chapter II-3. Let's say it is 75 feet. Then:

$$\frac{75 \times 120}{495} = 18.2 \text{ acres/minute}$$

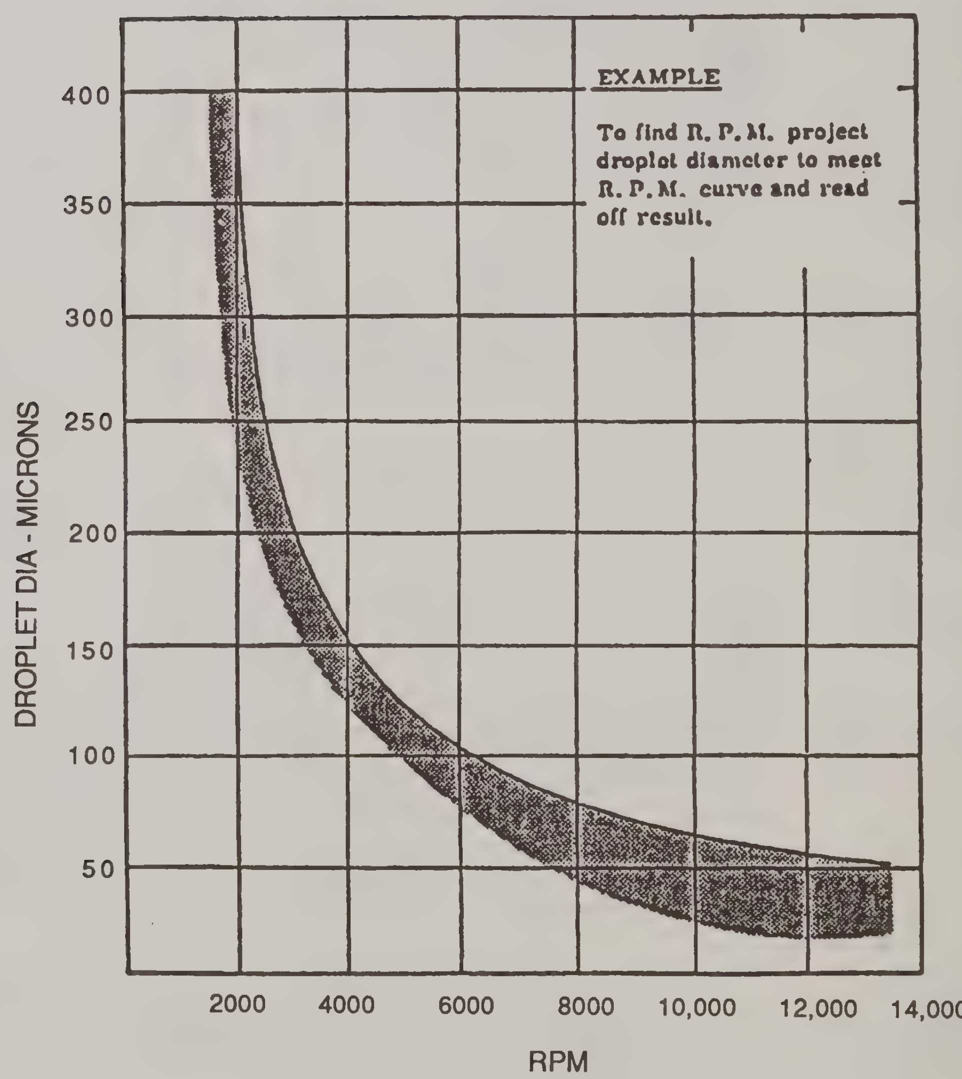

Figure II-1c. Micronair AU3000 and AU4000 Atomizers: Droplet size (DVO.5) variation with atomizer speeds. The graph is based on experiments done with water and should only be used as a guide. (Source: Micronair AU3000 and AU4000 Produce Literature)

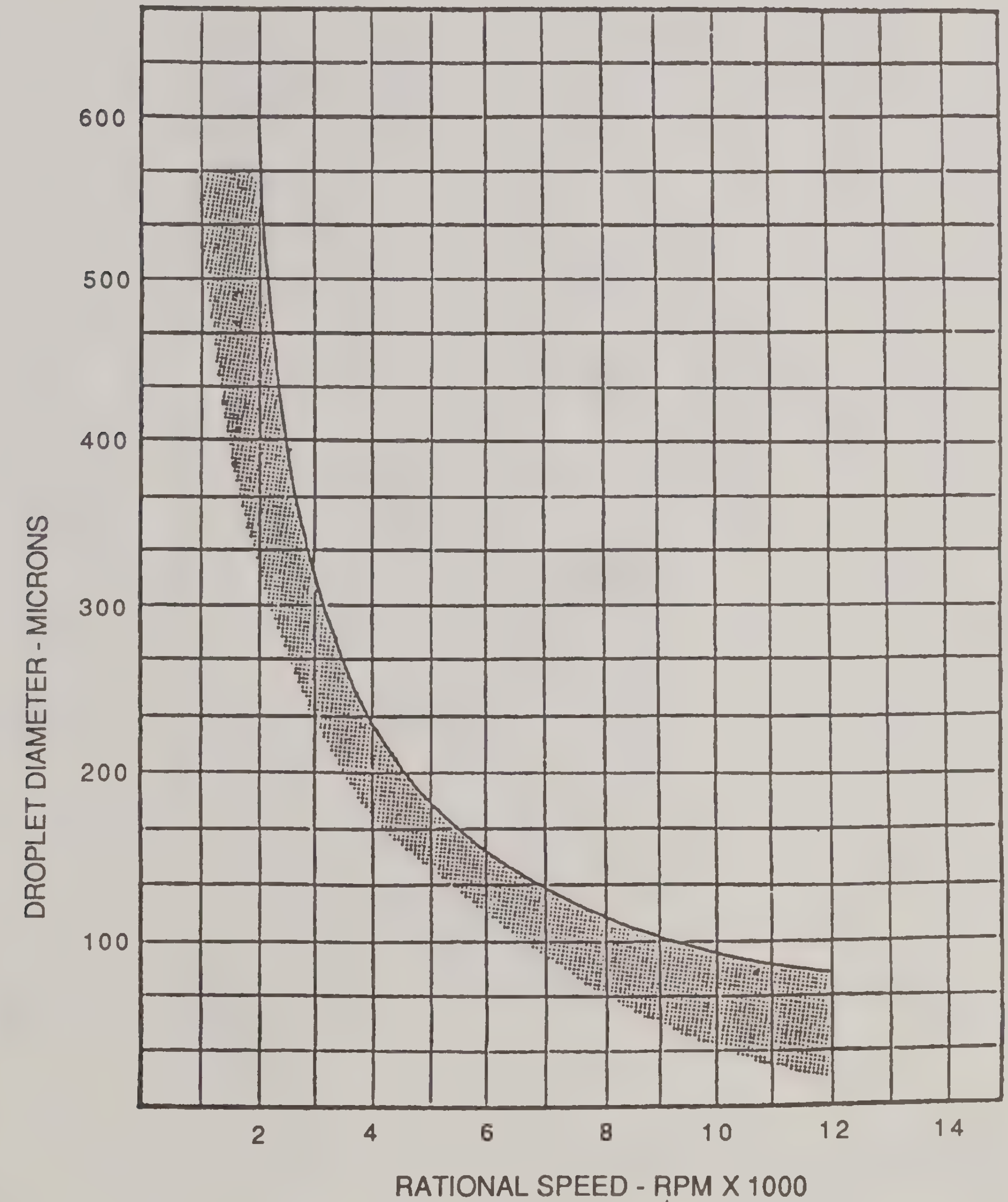

Figure II-1d. Micronair AU5000 Atomizer: Droplet size (DV5.0) variation with atomizer speeds. The graph is based on experiments done with water and should only be used as a guide. (Source: Micronair AU5000 Produce Literature)

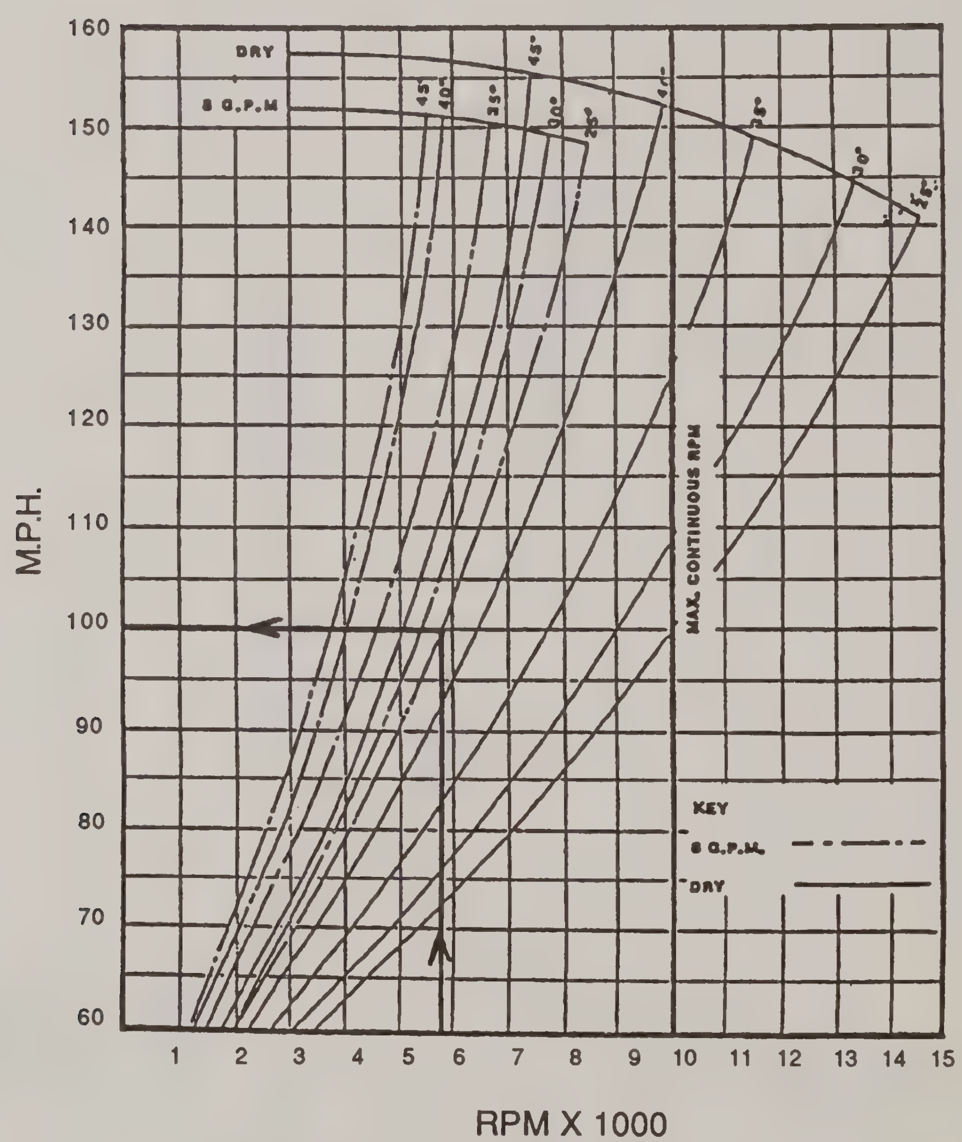

Figure II-1e. Micronair AU3000 Atomizer: Variation of rotational speed with aircraft speed and flow rate for different blade angles. NOTE: This graph only applies to 11-inch CBP289 twisted blades. (Source: Micronair Product Literature)

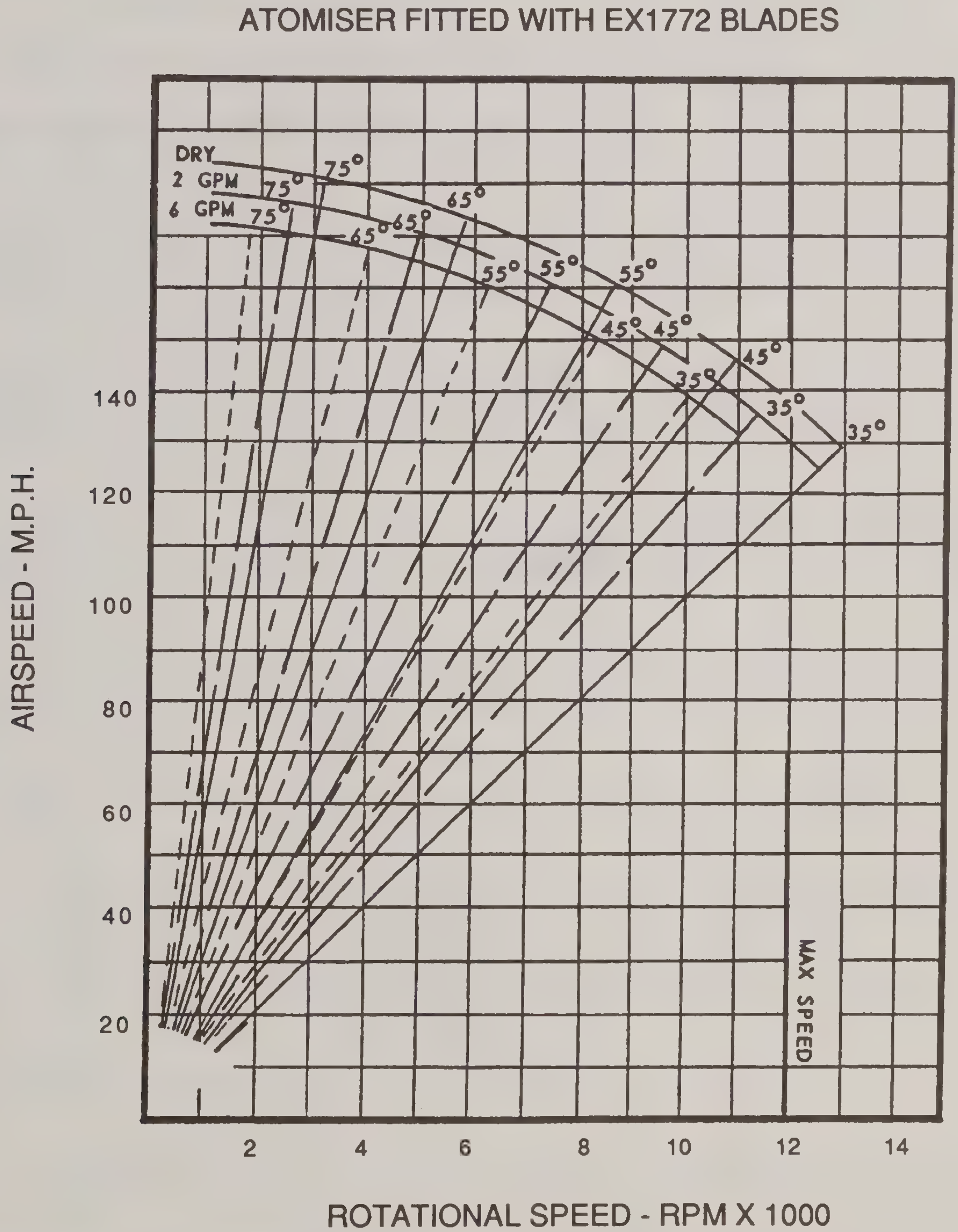

Figure II-1f. Micronair AU5000 Atomizer: Variation of rotational speed with aircraft speed and flow rate for different blade angles. NOTE: This graph only applies to EX1772 3.63 inch twisted blades. (Source: Micronair Product Literature)

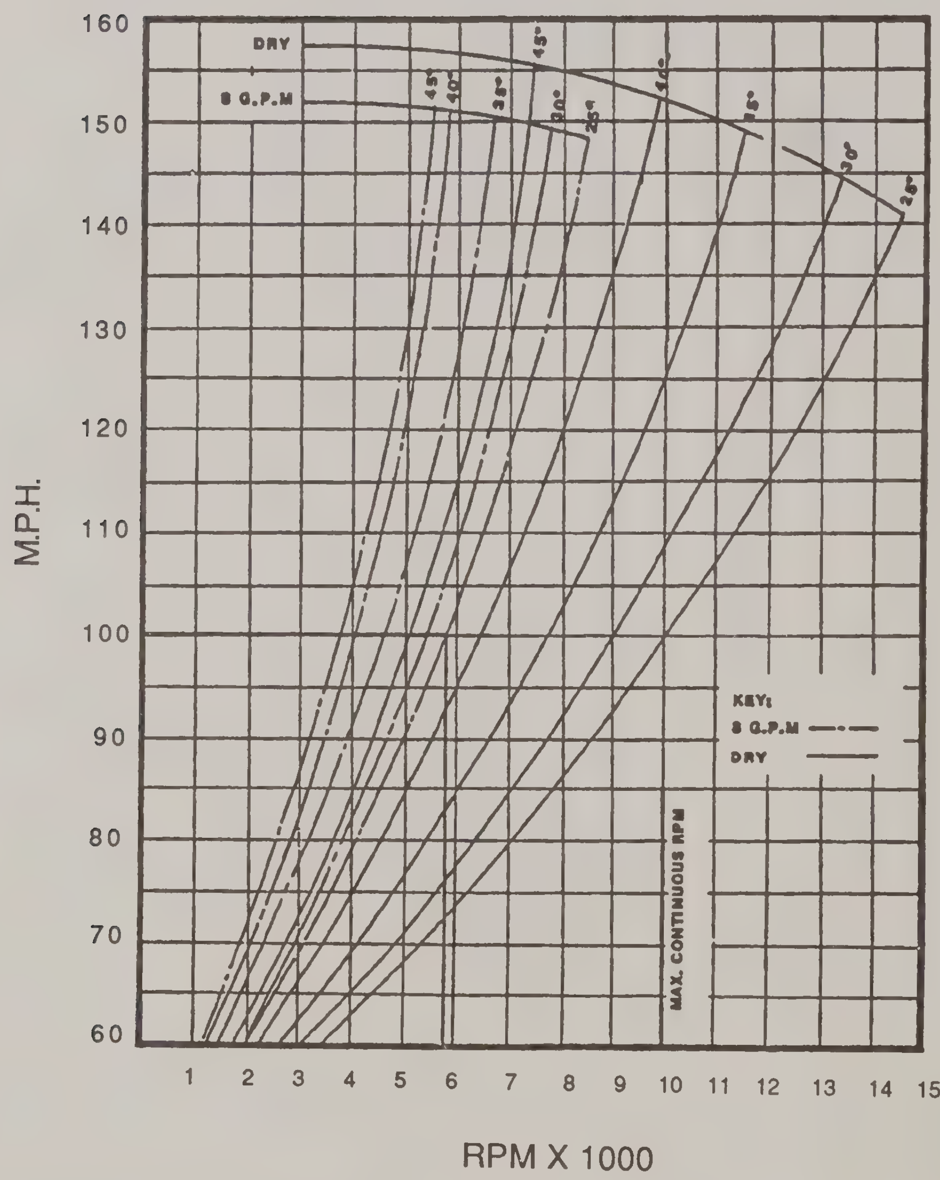

Figure II-1g. Micronair AU5000 Atomizer: Variation of rotational speed with aircraft speed and flow rate for different blade angles. NOTE: This graph only applies to EX1772 3.63 inch twisted blades. (Source: Micronair Product Literature)

Step 2. Calculate the required flow rate from Formula 2:

18.2 x 1 = 18.2 gallons/minute

Step 3. Assume that your configuration will have 40 nozzles. Then:

$$\frac{18.2}{40} = 0.46 \text{ gallons per minute}$$

Refer to Figure II-1b to obtain the desired flat fan nozzle. Either 8004 or 8005 nozzles can be fitted. With 8004 nozzles, a pressure of 50 psi will produce the desired flow rate, whereas, with 8005 nozzles, a pressure of 32 psi is sufficient. Go with the 8004 if a smaller droplet size is desired.

Calibration. The decision is to use 8004 nozzles. Forty gallons of water are added to the hopper and the spray system primed. The level is marked and the aircraft flown, applying the water for exactly 1 minute at 50 psi. On refill, only 16 gallons are required to fill the hopper up to the mark.

As there has been a shortfall in flow rate of 2.2 gallons/minute, each nozzle was spraying 0.40 gallons/minute (16/40). Five nozzles are therefore added (5 x 0.40 = 2.0 gallons), making the final flow rate around 18 gallons/minute, which is 1.1 percent short of the exact rate.

The process is repeated with the tank mix of Dipel. This time, 17 gallons of the Dipel tank mix are required to refill to the mark. What happened was that, even though the system was corrected for water, the increased viscosity of the Bt reduced the flow rate.

How does one ensure that the correct dosage rate is obtained? Several solutions are possible:

1. Add more nozzles. Each nozzle was spraying 0.38 gallons, so, an extra three nozzles would bring the flow rate to 18.24 gallons/minute. Remember that the aircraft will take a total of up to 50 nozzles.
2. Increase the application pressure. Usually, the pilot does this through his experience. However, the relationship between flow rate and pressure (Formula 4) can be used.

Rearranging Formula 4...

$$\text{Pressure 2} = 50 \times \left(\frac{18.2}{17}\right)^2 = 57 \text{ psi}$$

57 psi is too high a pressure. Centrifugal pumps become less efficient at higher pressures. In this case, therefore, Option 1 is the way to go.

If there had been a greater shortfall in output, due, for example, to a much more viscous material being used, more nozzles would have to be installed (this particular aircraft could take another five) or, if calculations showed that this would not have solved the problem, the nozzle type would have to be changed to one with a higher output. Remember that manufacturers' nozzle and rotary atomizer calibration data are usually based on experiments done with water and will be higher than empirically determined flow rates made with viscous pesticides.

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Delevan Company. 1989. Product literature. Lexington, TN

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Spraying Systems Company 1989. Product literature. Wheaton, IL

2. AIRCRAFT SPRAY CHARACTERIZATION

Karl Mierzejewski
and
Jon Bryant

Introduction

The objective of aircraft spray characterization is to visualize the swath pattern of the aircraft in order to establish whether an even pattern exists across the swath or to highlight a problem in a spray pattern such as a peak or valley. If necessary, adjustments can be made to create an even pattern.

This chapter describes the procedures for setting up a swath pattern determination and advises on problems that may be encountered during the run. More information on deposit assessment can be found in Chapter IV-3 and on the assessment of the spray patterns in Chapter II-3.

Aircraft Swath Pattern

The swath pattern of an aircraft should be trapezoidal in shape (Fig. II-2a). For the kind of low-volume applications being performed in forest spraying, the spray deposit should be as even as possible across the main part of the swath, with sloping edges on either side. Such a trapezoidal shape will give good overlap characteristics of adjacent swaths. It enables a safety margin to be built in for situations where wind effects or aircraft positioning errors result in imperfect overlaps of swaths. Undertreatment or overtreatment of areas will thus be minimized.

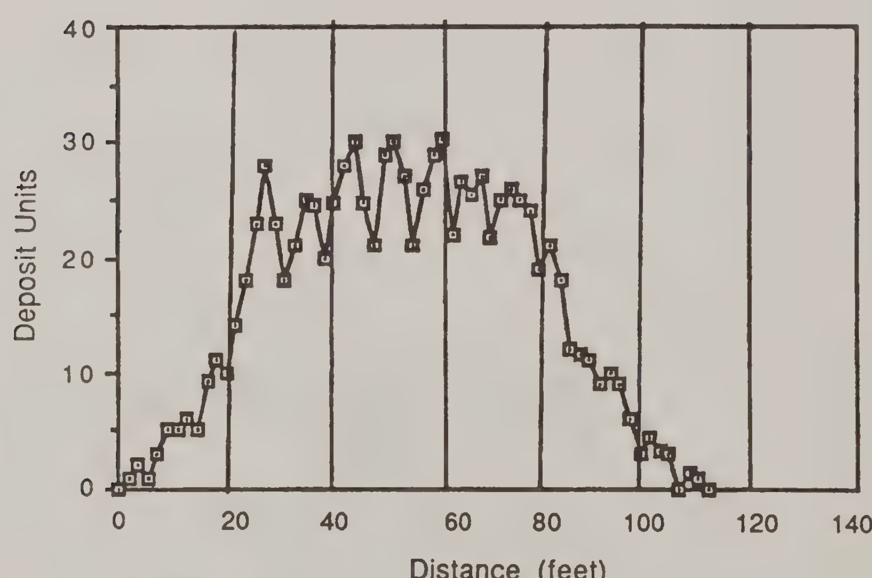

Figure II-2a. Idealized aircraft spray pattern for a 75-foot lane separation.

An ideal even swath pattern should show a uniform distribution of spray volume (active ingredient) across most of the swath. Droplet density should only be used for pattern estimation in the absence of techniques that measure dose directly. Droplet densities can give misleading dose representations at the extremes of the swath pattern where densities are high but doses are low because of the small droplet size.

An even pattern would only be apparent during no-wind conditions or where spray is directed into a light head- or tail-wind. Any crosswind component will tend to distort the shape of the pattern, leading to a tailing effect in the direction of the wind. This will be most pronounced with the smaller droplets, which are able to drift longer distances.

Lane Separation

The lane separation for any particular aircraft spraying forests at the required application rate of between 0.4 and 2 gallons per acre will already have been established based on past operational experience and characterization trials (Chapter II). A common misconception of the purpose of swath testing is that it is performed primarily to establish the lane separation that will be used operationally. What can happen is that turbulent or crosswind conditions result in a swath pattern that appears to be much larger than it typically is, resulting in the choice of too wide a lane separation to guarantee uniform coverage in most operating conditions and, consequently, underdosing of forest areas.

Remember that the aircraft wake, which determines the distribution of spray under still wind conditions, varies only very marginally between different examples of the same type of aircraft. The lane separations presented in this manual have been chosen to achieve adequate overlapping under a range of operating conditions using an optimal configuration of spray equipment. Therefore, consider very carefully whether your plan calls for the aircraft to fly wider than recommended in this manual; underdosed areas will probably result.

Since work rates and profits for a given aircraft depend on the lane separation, make sure that you specify the lane separation distance for each aircraft in the bid proposals to ensure fair bidding by each operator.

Procedures

Preparation. When performing a swath pattern assessment, you should already have established a lane separation for the aircraft and calibrated the aircraft on the basis of that value (Chapter II-1). (For a given airspeed, increasing the lane separation by a certain margin would entail increasing the flow rate also by the same margin, if the application rate is to remain constant). Before going to the airfield, make sure that you have the items listed below and that all equipment is functioning. (Avoid as much of the measuring or marking as possible during the actual characterization trial by advance preparation.)

- Adequate supply of spray cards. Pre-mark these cards with an indelible pen, showing a spray run number and card number.
- Tracer. Pre-measure this into plastic bags (powder) or plastic bottles (liquid) in units or subunits required for each tank load. (For example, if planning to use a 30-gallon load and needing 20 oz of tracer, then, weigh out 10 oz bags of tracer, and just add two bags to the tank.)
- Empty plastic bottles. If volumetric quantification is to be made (e.g., colorimetry, fluorometry, or rare metal), then, a sample of the spray mixture should be taken from the hopper after the application has been made and put into a 50-100 ml plastic container. This sample can be used to measure the ratio of tracer to active ingredient needed in later data analysis.
- Boxes or specially made collectors to hold sprayed cards until data analysis. (Many spray formulations, especially those containing oils, do not readily dry, so, cards must be kept separate to avoid cross contamination and smearing of the deposit.)
- Weather equipment. Calibrate this before the trial. Take spare batteries and cables where appropriate. Take a good compass, preferably, a sighting compass. A good type is the Suunto KB-20, available from the Forestry Suppliers Inc., P.O. Box 8397, Jackson, MS 39284-8397.
- Radios. Ensure that batteries are charged, and brief the pilot on the frequency to be used and the procedure for flight and for aborting spray runs.
- Collector stands. Make sure to have collector stands to hold the collector cards off the ground. Pre-mark the sampling area to help locate the spray line quickly in the case of changing wind directions (see below).

- Smoke bombs. Use 3- to 4-minute duration smoke bombs to help the pilot locate the center of the card line and to judge the direction and turbulence of the wind. (These can be purchased from Forestry Suppliers, Inc.)
- Miscellaneous supplies, such as pens and notebooks. Make plenty of notes about weather conditions at application time (e.g., was there an overcast) and on observation of the way the spray cloud settled out. (An example might read "seemed like the cloud fell to one side of card line. Wind changed direction before small droplets fell. Check for extra wide pattern width. Looked like unfilled spray pattern beneath fuselage.") These kinds of comments are invaluable evidence when you later trying to interpret the shape and width of the patterns observed. Notebook use also encourages observations on causative factors influencing spray patterns and the resulting effects.

Target material. Refer to Chapter IV-3, for choice of target collectors. In most cases, glossy white cards positioned near or just above the ground are suitable for this purpose.

Spray material. Whether water or the actual operational tank mix is used to perform a spray pattern characterization depends on the nature of the material. In cases where an emulsifiable concentrate mix made up with more than 2 volumes of water is used, water may be used for the runs. However, if viscous materials (such as Bt), particulate, or concentrated materials whose volatilities differ markedly from water are being used, then the final tank mix should be used. Generally, it is better to work with the tank mix, as long as the material is not very toxic and not in short supply.

Tracer. In order to visualize the deposit, a tracer (usually colored) is added to the tank mix. Examples of tracers required for different chemicals and formulations can be found in Barry and others (1978). If water-sensitive or oil-sensitive papers are being used, no tracer need be added. Examples of sensitive papers required for different materials can be found in Dumbauld and Rafferty (1977).

It is important that a good contrast exist between the droplet stains and the collecting surface. A simple test with a "Windex"-type window cleaner bottle can be used to spray test cards, which will then be able to reveal whether or not sufficient tracer has been added.

Tracers that are soluble in both aqueous and oil-based formulations do not exist. In most cases, aqueous formulations are used in gypsy moth control, so, an aqueous tracer should be added. Remember that Bt oil-based formulations are aqueous in nature when mixed with water, although they will not dissolve water-soluble tracers when in the undiluted state. Some examples of aqueous fluorescent tracers are:

- Rhodamine WT dissolved at 2 grams/liter. (Note that Rhodamine B does not have EPA approval). Rhodamine is crimson colored and gives good visual contrast under normal light and UV light. (Source: Keystone Aniline Corporation, Chicago, IL)
- Brilliant Sulfaflavine (BSF) dissolved at 2 grams/liter. BSF is bright yellow and gives brightly colored stains under UV light. However, it does not give good contrast in normal light. (Source: Organic Dyestuffs Corporation, East Providence, RI)
- Food dyes. They have the quality of being nontoxic, although a lot of dye is normally required in order to obtain good stain contrast.

- Other aqueous fluorescent products including Avilon navy blue (1 percent), Maxilon blue (1 percent), Helios OB (2-10 grams/liter), a transparent fluorescent dye available from Ciba-Geigy and Automate Red B.

Collector array: length and spacing. There are two questions to be considered: "How long should the card line be to catch the whole spray pattern?" and "How wide should the cards be spaced to get an adequate measurement of the shape of the pattern?" These questions are answered below.

When spraying from 50 feet (a typical spray height for single engine aircraft), even a slight crosswind component of 2 mph will drift droplets of 100 µm a considerable distance (170 feet) and larger droplets (greater than 200 µm) by up to 50 feet. Therefore, it is necessary to extend the cards well to either side of the centerline of the aircraft to make sure that the swath is caught.

Guidelines exist for collector line lengths for aircraft involved in forest spraying; line length = 10 x flying height (Kautz and Ekblad 1984). This formula is quite generous. For single-engine aircraft, a 400-foot line is adequate when a flying height of 50 feet is used. For multi-engined aircraft, the line should be increased to 600 or 800 feet or further if a 100-foot flying height and large multiengine aircraft are being tested.

Collectors should be placed in a straight line at 6-foot (2-meter) intervals in order to obtain a good resolution of the pattern. A 12-foot (3.5-meter) spacing gives a coarser picture. This spacing should be used only for the wide patterns from multiengine aircraft or, if the wind direction is steady and runs are being made directly into wind or there is negligible wind, the center 200 feet may be laid out at 6-foot intervals, with the outer 100 feet on both sides laid out at 12-foot intervals.

The orientation of the target line should be perpendicular to the wind. Getting the direction right is often not easy when trials are conducted early in the morning. As the sun rises and heats up the ground, the wind direction may veer or back considerably as vertical mixing in the atmosphere takes place. In such cases, collector lines can be laid out to anticipate changes in the wind direction or the crosswind spray technique used (described in Section 9 below).

If a number of trials are being made at the same location on different days, it is worthwhile to take time to do some site preparation. Lay out a compass rose 200 feet in diameter, using wooden pegs labeled with direction every 20 degrees around the circumference of the rose. Fasten the middle of a length of strong nylon string, the length of the collector line, to a wooden stake in the center of the rose. Pre-mark this string with the positions for the collector cards, say, every 6 feet. Tying a piece of colored nylon ribbon to mark card positions is good for quickly finding card positions and for numbering the positions using an indelible pen. This arrangement is shown in Figure II-2b.

With one person on either end of the string, new card line directions can be matched to the current wind quickly by simply picking up the ends of the string and walking to the appropriately marked peg in the compass rose. Cards are then repositioned down the length of the string at the premarked positions. Without this technique, it will be hard to keep pace with new card layouts to match the quickly changing wind directions that often plague a spray trial.

Meteorological monitoring. Meteorological monitoring is described in detail in Chapter IV-1. In brief, wind speed and wind direction at 2.5 meters (8 feet) should be constantly monitored. Wet and dry bulb temperatures should be measured at 10-minute intervals, and at the time of aircraft overflight.

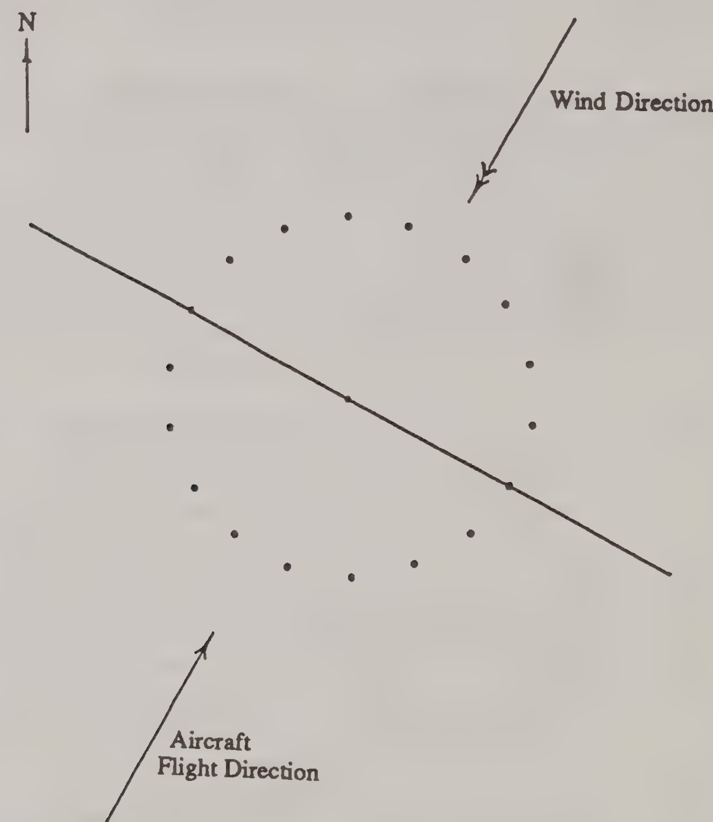

Figure II-2b. Compass rose arrangement for layout of collector lines. Radius for circle is 100 feet.

If temperatures increase beyond 80°F, or the humidity falls below 50 percent with temperatures higher than 60°F, the spray trials should be suspended until conditions become more favorable for spraying aqueous sprays.

Equipment for monitoring ranges from the simple and inexpensive to elaborate and expensive. A list of the minimum equipment required includes: a wet and dry bulb sling psychrometer (inexpensive); wind speed-pith ball (e.g., Dwyer Portable wind meter) (inexpensive); sighting compass and ribbon on a stick (inexpensive); hand-held wind measuring equipment (inexpensive); and purpose-built pattern measuring equipment like the Swath Kit or stand-alone weather sensors recording data logging equipment (expensive).

Replicates. (How many times should the aircraft be tested?) The question, "How adequate is the shape of the pattern--is it even or does it have problems?", can be quickly answered with single runs, changing the nozzle positions as necessary between runs. When satisfied that the pattern meets requirements, make additional runs with the same configuration to build an average or typical pattern for that configuration. This is required because the passage of droplets between release and sedimentation is subject to complex atmospheric influences. The swath pattern obtained after one run should not be considered as sufficient to establish the true pattern. A minimum of two independent runs

should therefore be made. Putting out two or more collector lines for each pass is only worthwhile if sufficient resources are available to analyze each of the card lines. Remember that these do not constitute an independent replicate.

Spray trial procedures. Make sure the pilot is well briefed on what has to be done. This is especially important if there is no ground communication between the aircraft and ground crew. In such a situation, agree for clear signals to be made to the pilot by the flaggers in case an abort due to poor wind conditions is required. The ground crew should continually monitor the weather while the aircraft is airborne and advise the pilot when a run is possible.

If a nontoxic product is being sprayed, position flaggers 200 feet on either side of the spray card line, in line with the wind. If toxic products are being sprayed, position flags in the same areas. Using smoke bombs is useful to indicate current wind conditions, since both ground crew and pilot can see changes in the smoke quickly.

Spray switch-on and switch-off should be done, bearing in mind the passage of small droplets due to wind drift. Flying height and wind strength directly affect the droplet distances from the centerline. Switch-on should be made 200-300 feet away from the target line when flying into wind at 50 feet. Switch-off should be made at 300 feet in still wind conditions, but should be extended according to the strength of the fresh wind. As a rough guide, in 8-knot (9 mph) winds, the aircraft should fly about 1,000 feet past the card line. In stronger winds, should you be characterizing the aircraftt?

After a run has been made, wait at least 5 minutes before picking up the cards. It takes this much time for the small droplets to settle out and allows the droplets time to dry on the cards. During this time, do not walk around or upwind of the cards.

Crosswind spray technique. In order to obtain a true picture of a cross-sectional slice across the swath, the aircraft must be flown directly into wind. In cases where a crosswind exists, the pilot must still fly into wind, but at an angle to the line of collectors. The pilot should still cross the target line in the center (Fig. II-2c). Such a procedure cannot be used under all wind conditions. Once the wind direction is more than 40 degrees off the card line, the card line should be realigned perpendicular to the wind.

Under crosswind conditions, the spacing between the cards has to be recalculated using Formula 1.

Formula 1
Corrected distance = actual distance x cos(angle between flight path and perpendicular to cards)

An example calculation using this formula is:

Card line = East-West (90x/270x)
Perpendicular = North-South (0x/180x)
Wind direction = 030x
Card spacing = 6 feet

Corrected card spacing = 6ft x cos(30°)
= 5.2ft

To obtain a crosswind pattern, however, fly the aircraft across the cardline, heading north, but offset the centerline into the wind by a hundred feet.

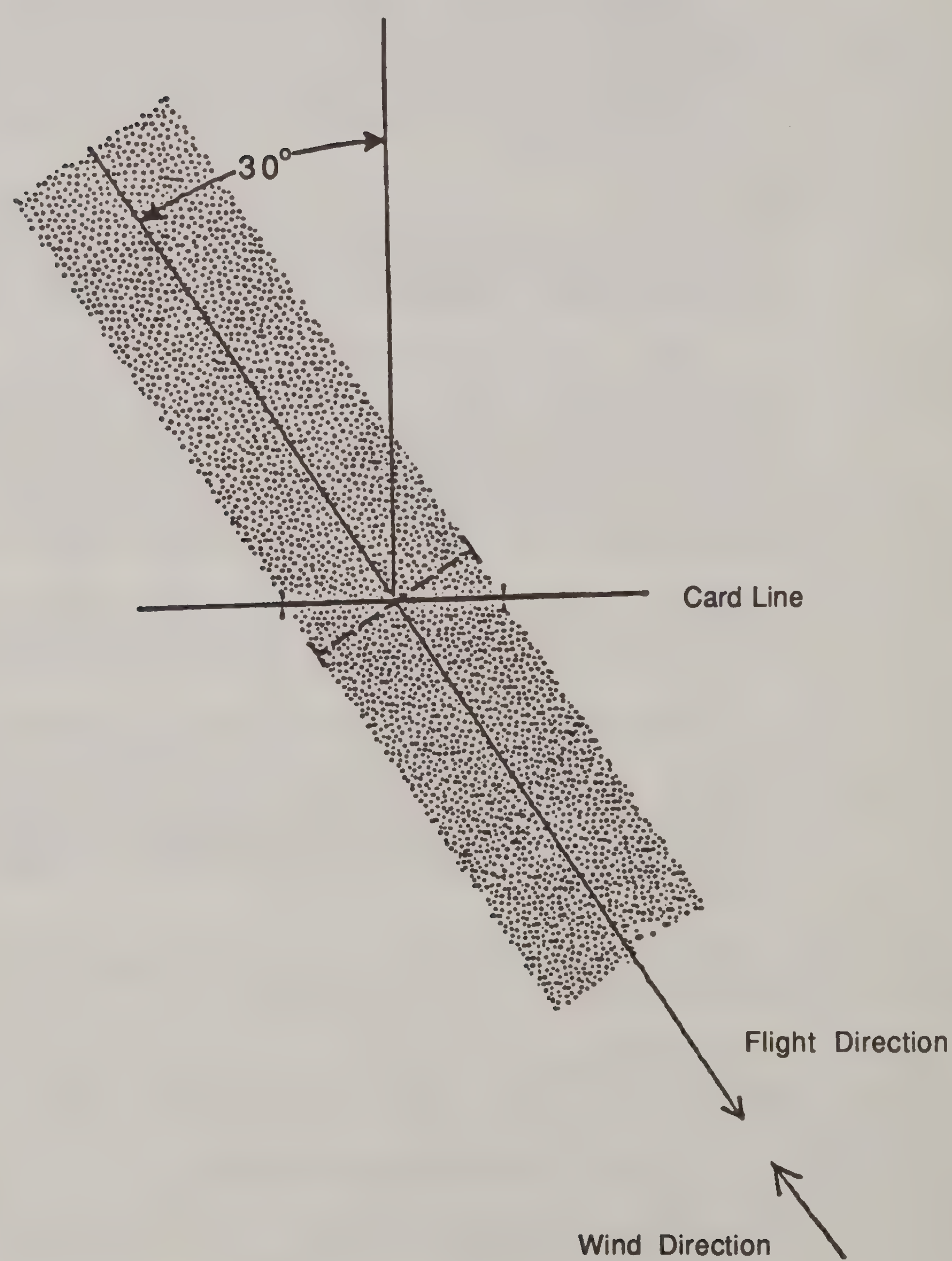

Figure II-2c. Flight direction adjustment in crosswind situations.

Conclusions

This section of the manual gives instructions on how to obtain a good 'picture' of an aircraft swath pattern. Refer to Chapter III-1 on how to assess the spray deposit and to Chapter II-2 to troubleshoot any inconsistencies that may exist in an individual swath pattern.

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Kautz, J.; Ekblad, R.B. 1984. Analysis of spray deposit cards sensitive to non-dyed mixes. TI 3E32P44, Missoula, MT: Technology and Development Center.

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3. SPRAY PATTERN ASSESSMENT

William Yendol
and
Michael McManus

Introduction

To efficiently deliver pesticide to a crop by air, it is important to be able to measure the spray output from the aircraft with respect to rate/acre, swath width, evenness of application and, with liquid sprays, drop size and density.

Aircraft Swath

The concept of "swath" is an aspect of aerial application that is often controversial and open to misunderstanding. In some situations, it can be difficult to determine precisely the swath width an aircraft is producing. Weather conditions can change during the time of the determination, leading to false assessments of swath width. Even using another formulation or changing the total spray volume to be applied can result in noticeable swath width differences. Changes in forward spray speed, height, and weight of the aircraft will also influence the swath width, as will the aircraft's geometry.

Accurate spray placement depends upon the ability to repeat the total system. Thus, in establishing a swath pattern for an aircraft and its spray system, the same airspeed, spray height, spray pressure, nozzle location, and (if possible) proposed formulation should be used consistently.

For a more comprehensive review of swath width determination and pattern testing, the following publications should be consulted: Dumbauld and Rafferty 1977, Kuhlman and Cress 1981, Skankland and Tucker 1980, and O'Neal and Brazelton 1984.

Swath width. Generally, swath width refers to the width of the deposition of a spray or other materials on the ground or target area. As the aircraft releases the spray or other materials, a spray cloud is formed. With time, this cloud moves downward and outward toward the crop or ground level being treated. Eventually, the spray material falls on the crop (or objects) being treated, or is lost from the target site as drift.

Effective swath. An effective swath can be considered that portion of the total swath width that receives (as practically as can be) at least the correct minimum pesticide dosage or the minimum dosage that will reduce the pest population below a desired level or economic threshold. Thus, establishing an effective swath width enables the spray applicator to distribute active ingredient on the target that is above the minimum dose. The applicator can also then determine the flow rate required, the appropriate nozzle size, and the area that will be treated per hour. In most cases, the spray droplet distribution on specific crop target surfaces has not been determined.

As shown in Figure II-3a, the total swath width would be the spray pattern from zero to zero deposit, as compared to the effective swath width. Aerial application treatments using the total swath width would not account for any overlapping, resulting in an uneven spray distribution. The effective swath width constitutes that part of the total swath containing most of the pesticide, and its selection is important in the overlapping process (Fig. II-3b).

Pattern Testing

An aircraft spray pattern should be checked to assure correct spray distribution across the swath width prior to application. Usually, this method depends upon the visual estimation of pattern uniformity and effective swath width. (Refer to Chapter II-2 on how to characterize an aircraft.)

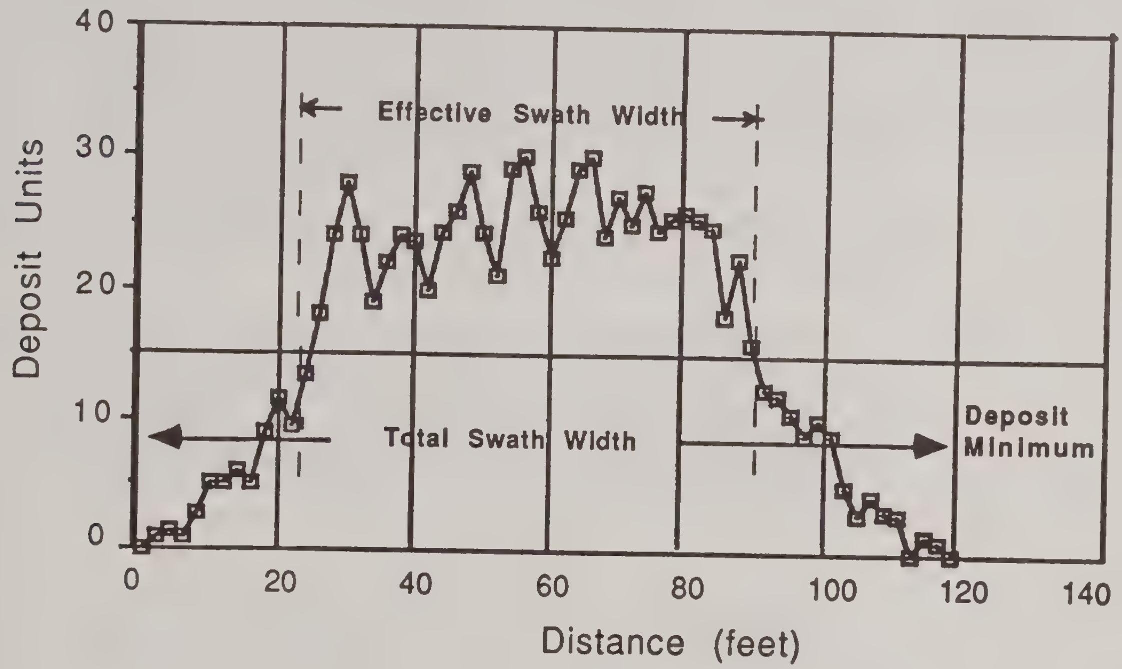

Figure II-3a. An example of the typical spray deposit pattern illustrating the total and effective swath widths.

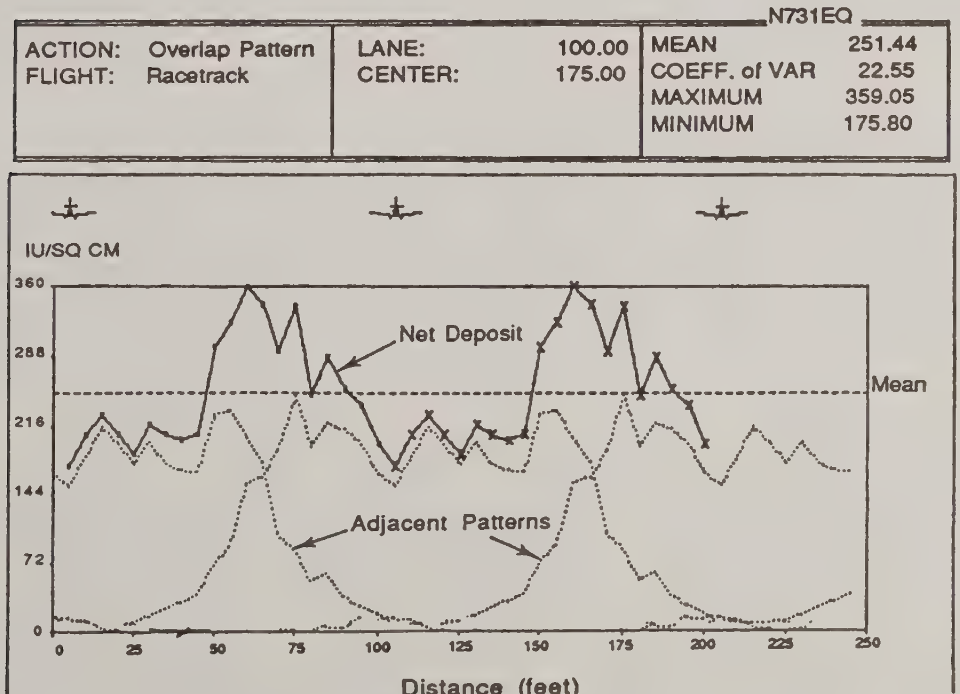

Figure II-3b. A typical computer developed overlap pattern using a single swath pattern with a 100 foot lane separation applied by the race trace method.

Pattern Visualization Methods

When other quantitative techniques are not available, the useable swath width or excessive spray material from the nozzle(s) may be visualized (without a magnifying lens) by viewing the spray coverage on each card and assigning a value between 0 and 10, with 10 being the card that has received the greatest spray coverage and 0 value for the card that had no detectable spray droplets. Those cards that have received only half the relative spray coverage would be assigned the value of 5. This evaluating technique can best be achieved by spreading the spray cards (with their card line position marked on the reverse side) over a flat area, arranging them so that the most densely covered card is to the right and then in a descending order to the least densely sprayed card. Assign the appropriate rating values from the 0 to 10 scale to each card, and write the rating on the face of the card.

Prepare a swath width graph using the rating from 1 to 10 on the vertical axis and the card location number on the horizontal axis (see Fig. II-3c). Graph paper can also be used for plotting swath patterns. Place a small circle or dot at the appropriate rating number over the respective card location number. After this has been completed for all the cards, draw lines through the various dots connecting them in a continuous pattern.

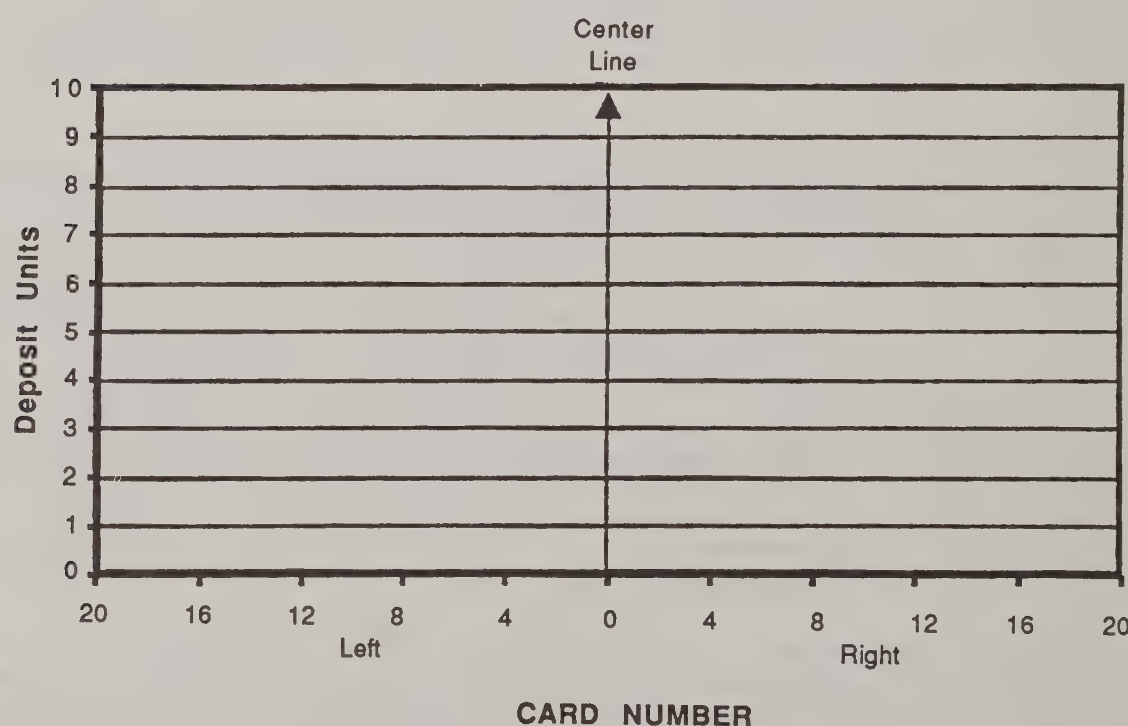

Figure II-3c. Suggested type of graph used for plotting the relative deposit and estimating the swath width of an aircraft and its spray system.

Although this method will not provide the applicator with a quantitative estimate of the spray material being released from the aircraft, it will provide some indication of where there may be a nozzle overloading (peaks) or lack of nozzles (valleys) and other unsuitable characteristics of the swath. Also, be aware that this method tends to overestimate the amount of material at the edges of the swath, making the swath appear wider than it actually is.

Observe the entire collector line with reference to the uniformity of deposition or droplet density. Particular attention should be directed to the areas on the card line that show a light deposit density near the center line or an uneven density toward the outer portions of the swath. Where light or heavy deposits are found, nozzles can be added, turned off, or moved to another boom position. Movement of the nozzle to fill in pattern gaps or overly heavy deposit areas (peaks on the graph) is largely a trial-and-error procedure, but the following points will help in establishing which areas of the boom need adjusting.

The following are some typical fixed-wing problems affecting swath width distribution:

1) A light droplet density area or reduced deposit on the right side of the fuselage caused by "prop wash" (Fig. II-3d). This distribution pattern can be corrected by adding nozzles on the right wing 2 to 4 feet outward from the center line.

2) A heavy droplet density or deposit occuring on the right side of the fuselage. This is usually caused by over-compensation for the prop wash (Fig. II-3e). This can be corrected by removing some nozzles on the left side of the boom near the fuselage.

3) A deposition pattern showing the typical turbine powered aircraft at an application speed of 105 mph (Fig. II-3f). Note the pattern uniformity. Figure II-3g illustrates the effect of increasing the speed of the same turbine powered aircraft to 135 mph. The 30 mph increase in application speed causes an increase in tail loadings and a subsequent increased vortex being produced from the horizontal stabilizer. A "rooster tail" effect results from this increased aircraft speed.

4) An irregular pattern distribution occurring at the outer margins of the swath width caused by wingtip or rotor-wash (Fig. II-3h). This can be corrected by turning off some of the end nozzles and repeatedly checking the swath pattern until the edges of the swath show the correct slope. Nozzles located beyond the 3/4 span position will produce spray material that will be caught up in the wingtip vortex and could result in drift problems.

5) Aircraft height effects. This is an important factor affecting the spray distribution pattern. As an example (Fig. II-3i), a height increase tends to decrease the average deposit and increase the lateral spread, which can result in an increase in the effective swath width. Note that the flow rate through the system will have to be increased proportionally. A reduction in height would have the opposite effect. As the aircraft moves closer to the top of the canopy, the wingtip swirl is enhanced, and peaks of deposit can occur just outboard of the tips, leading to a more uneven distribution but less of a loss in lane separation than might be expected. Water-mixed sprays on forests are usually applied from one- to two-wingspan heights.

6) Crosswind effects. These can be quite complex. The whole mass of the emission is transported sideways from below the aircraft (Fig. II-3j). In light crosswinds (2-5 mph), the upwind part of the swath is moved less than would be expected because the windward tip vortex causes a velocity opposing the wind effects. This effect produces a peak deposit in the distribution and then a sharp cutoff on the upwind side. On the other side, the vortex effect aids the downwind movement of spray particles, particularly the smaller droplets. This results in a long tail of deposit downwind. Consequently, the spray deposit becomes less dense because the material is spread over a greater lateral distance, resulting in a greater swath width. Determinations of swath widths made under such crosswind conditions should not be used as the basis for establishing the effective swath width, especially if droplet density is used as the method of assessing deposition.

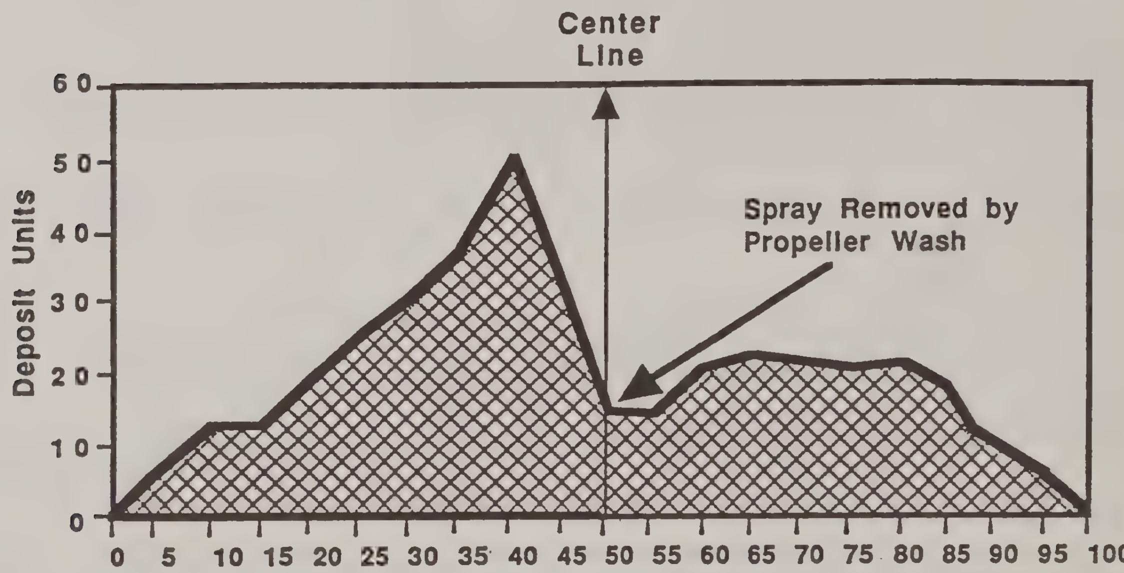

Figure II-3d. Deposition pattern illustrating a classical prop-wash problem.

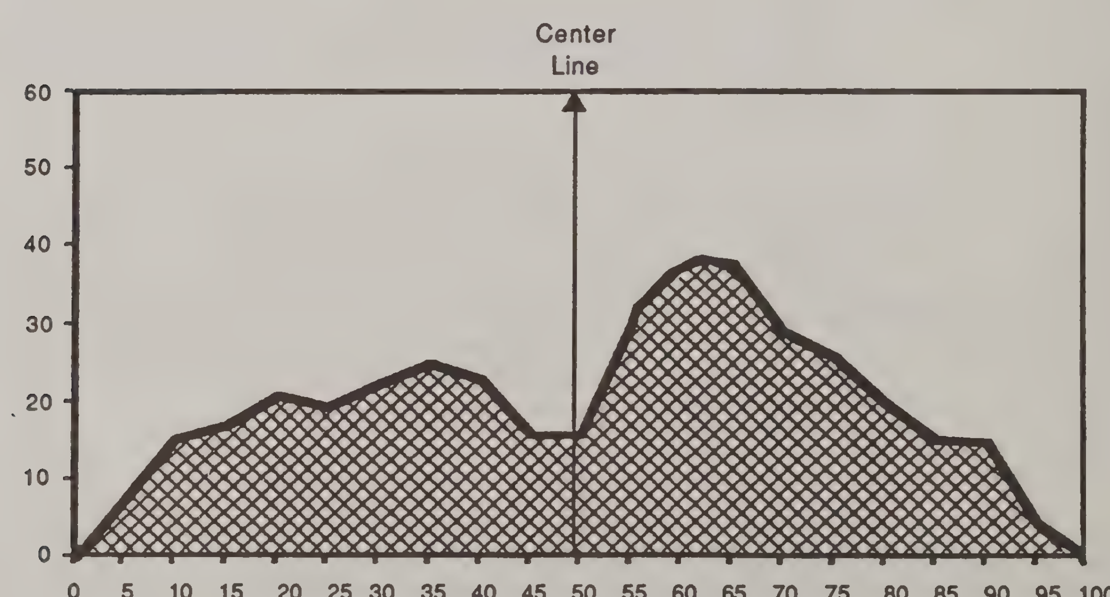

Figure II-3e. An uneven deposition pattern as a result of overcompensating for the prop-wash effect.

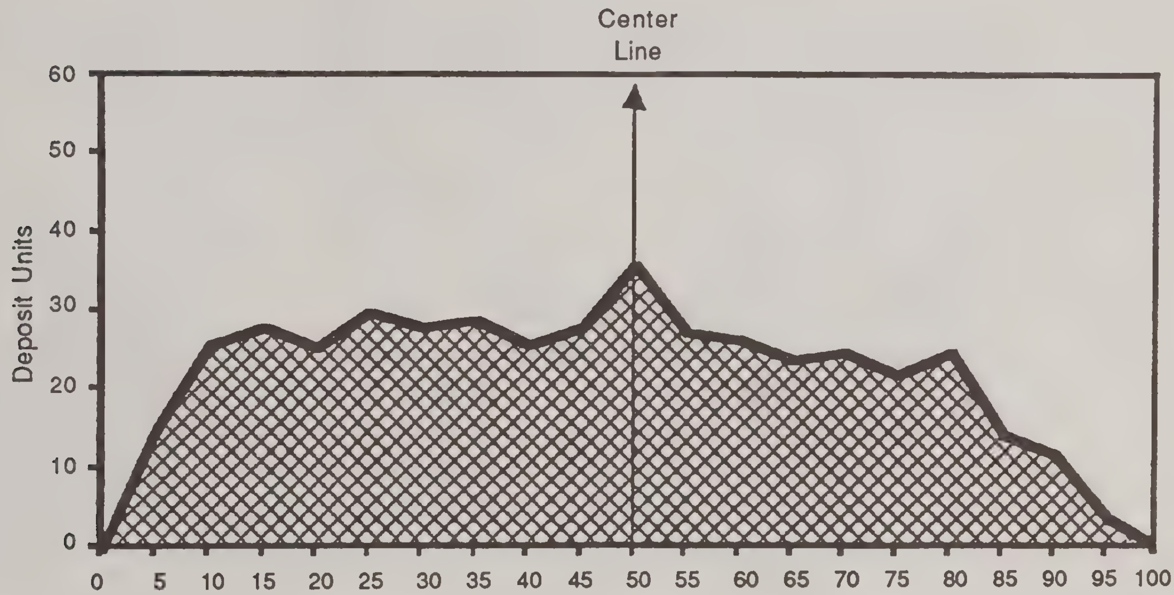

Figure II-3f. Deposition pattern for a turbine-powered aircraft with an application speed of 105 miles per hour.

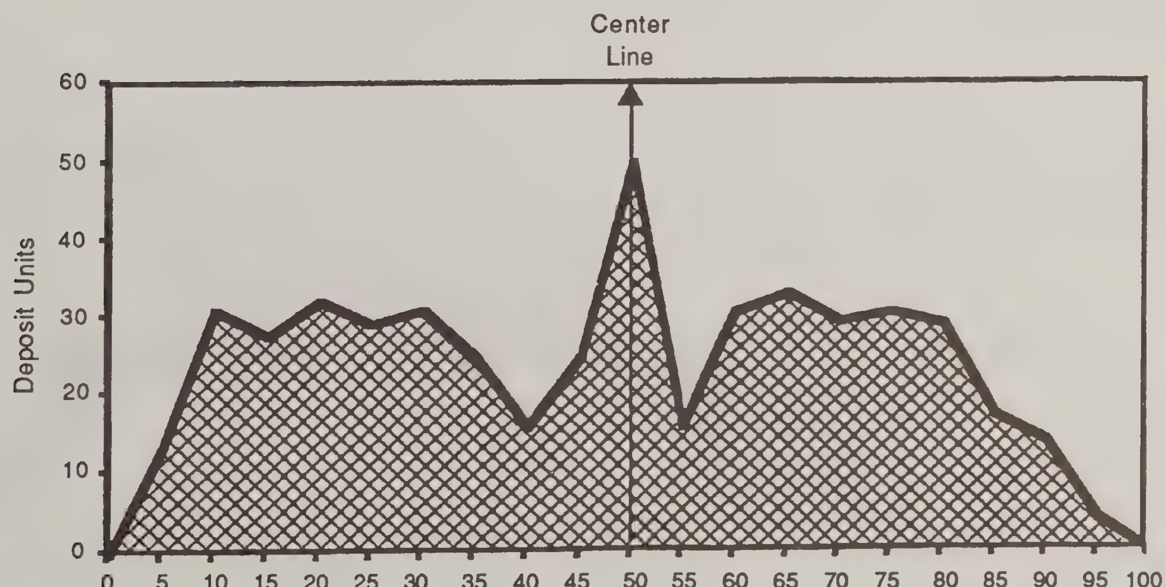

Figure II-3g. Spray distribution pattern of the turbine aircraft at a higher speed of 135 miles per hour.

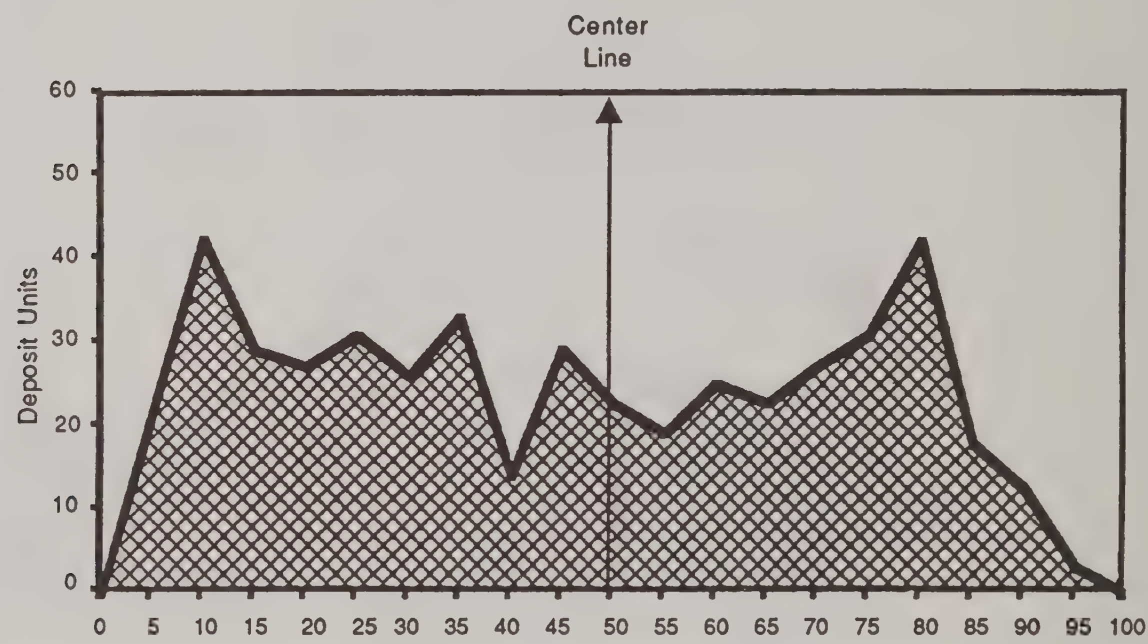

Figure II-3h. An irregular deposit distribution pattern as a result of wing tip vortex effect.

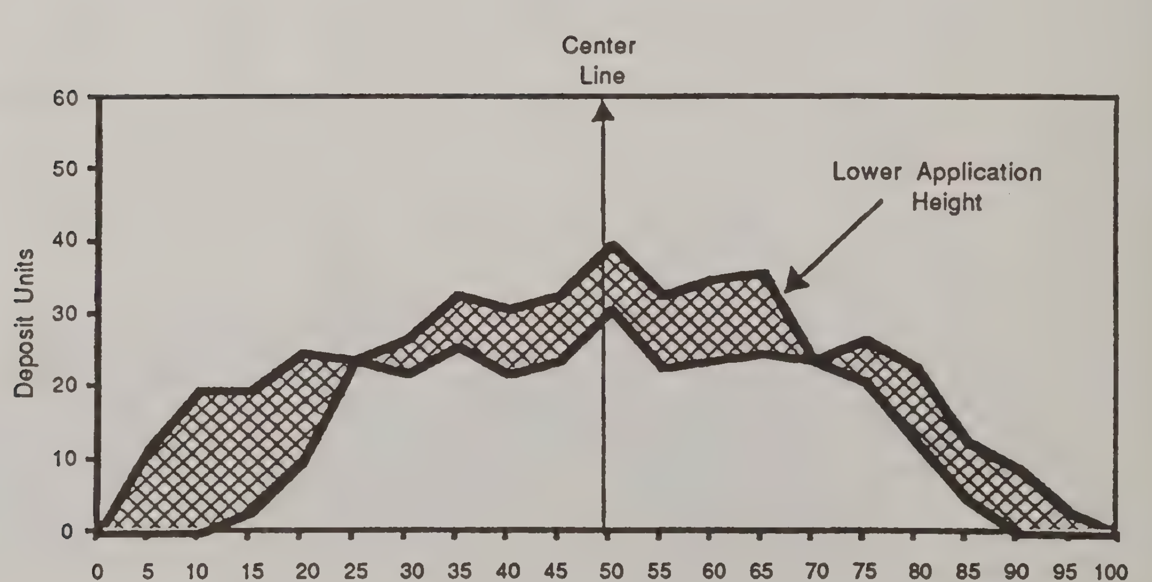

Figure II-3i. Effect of aerial application height of the aircraft on the overall spray distribution pattern.

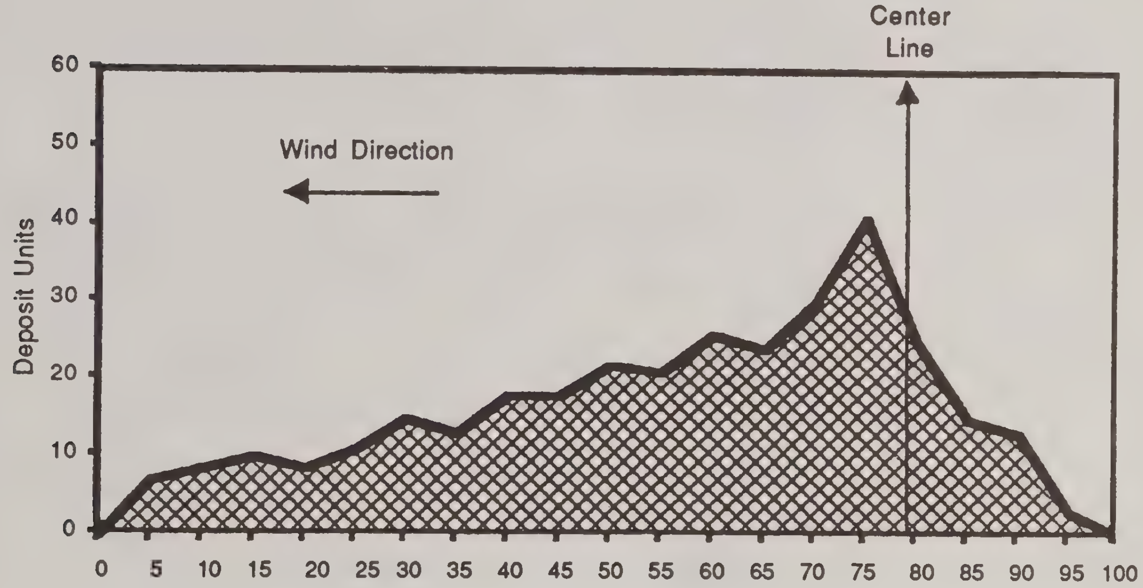

Figure II-3j. An uneven spray swath distribution pattern as a result of crosswinds.

7) Large irregular droplets on the collection devices. This indicates leaks in the system. Checking the specific area along the line will give a clue as to where the leak may occur.

When determining swath widths, keep in mind that small-to-medium droplets may produce wider swath widths than larger ones. These smaller droplets are displaced outwardly by the aircraft wing vortices to a greater extent than the larger droplets. The large droplets are heavier, consequently, they fall more vertically and impact on the target sooner. The vortex contribution by the wing, among other things, is a function of the wing design, wingspan, wingloading, and engine power.

A suggested standard uniform procedure for measuring and reporting application rates and distribution patterns from agricultural aircraft is found in Appendix A.[3]

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3 American Society of Agricultural Engineers Standard: ASAE S 386.2

Lane Separation Selection

The most important operational parameter in aerial application is the flight lane separation, which is the distance between successive flight paths. Lane separation data for various aircraft are presented in Table II-3a. These are based on USDA-APHIS recommendations and may be followed as guidelines in establishing spray contracts. These figures were determined after many years of APHIS operational programs. Increasing lane separations beyond these values on the basis of obtained swath patterns will likely lead to underdosed areas between adjacent lanes.

Table II-3a--Examples of allowable swath spacing in aerial spraying operations established for various aircraft by USDA-APHIS (USDA-APHIS Operation Manual).

Aircraft	Malathion Sevin 4-Oil All Oil Mixtures Swath Width (feet)	All Water Mixtures Swath Width (feet)
CATEGORY A - FIXED WING		
Douglas DC-4/DC-6	550	400
Douglas DC-7	650	500
CATEGORY B - FIXED WING		
Curtiss C-46	500	350
Douglas DC-3/C-47	400	300
CATEGORY C - FIXED WING		
Grumman TBM	250	200
Turbine Thrush	150	100
Turbine Air Tractor	150	100
Turbine Ag-Cat	150	100
Thrush (800 hp & above)	150	100
Ag-Cat (800 hp & above)	150	100
Twin Beech H-18/C-45	150	100
CATEGORY D - FIXED WING		
Cessna (all 188 Models)	100	75
Thrush/Snow/Air Tractor (Piston engined)	125	100
Ag-Cat (A Models)	100	75
Ag-Cat (B & C Models)	125	100
Piper Brave	100	75
Piper Pawnee (230-260 hp)	100	75
Stearman (450-600 hp)	100	75
Weatherly 201A	100	75
CATEGORY E- FIXED WING		
Callair (150-180 hp)	75	50
Piper Pawnee (150-180 hp)	75	50

Table II-3a. continued.

Aircraft	Malathion Sevin 4-Oil All Oil Mixtures Swath Width (feet)	All Water Mixtures Swath Width (feet)
CATEGORY A - HELICOPTER		
Bell 204/205/212/214	150	120
Sikorsky S-58-T	150	120
CATEGORY B - HELICOPTER		
Sikorsky S-55-T	120	100
Alouette III	120	100
CATEGORY C - HELICOPTER		
Alouette II	100	75
Bell Jet Ranger 206	100	75
Hughes/MD 500	100	75
Hiller 1100	100	75
Hiller 12E Soloy	100	75
Bell 47 Soloy Turbine	100	75
CATEGORY D - HELICOPTER		
Hiller 12E	100	75
Bell 479 (Piston engined)	100	75

Assessment of the choice of lane separation can be carried out by actually flying several passes over an extended line at the required lane separation distance. Alternatively, the correct lane separation can be verified by taking the results of a single flight line deposit and overlapping the results at different spacings. With this method, the overall deposit across the field can be determined. An advantage of this method is that the distance can be varied using the same data in order to find the optimum lane separation.

The spray deposit pattern can be overlapped as though each pattern were identical to the previous run, with the flight path moved over to give the necessary lane separation (racetrack treatments). This method assumes that there is no difference in the deposit pattern due to changes in flight direction. Conversely, the spray pattern can be overlapped, assuming that the pattern up the field is the same as the downfield pattern but is reversed due to the changes in flight direction (to-and-fro treatments). When plotting a to-and-fro method of treatment, use the latter method if the swath patterns were obtained under zero-wind conditions or by flights made directly into wind. Otherwise, use the former method. This is because wind effects on the spray

will be much stronger than aircraft effects, and whichever direction the aircraft flies, the pattern distribution will still be downwind. Conversely, in minimal wind conditions and where the spray is mostly in large droplets, the aircraft effects tend to dominate.

Uniformity of Spray Distribution

One indicator used to determine the degree of uniformity of the spray distribution is the coefficient of variation (CV). The CV is found by determining the standard deviation of the resulting overlapped spray deposit at a particular lane separation and dividing it by the mean. This quantity is expressed as a percentage and is calculated as follows:

$$CV = \frac{\Sigma(X_i - X_m)^2/(n-1) \times 100}{X_m}$$

where: Xi = overlapped deposit between flight lanes for each card location
Xm = mean of overlapped deposit
n = number of samples in overlap pattern.

Determination of the CV for a particular lane separation can usually be accomplished with the aid of a scientific pocket calculator, especially the kind that can be simply programmed to determine the mean and the standard deviation.

For most situations, CV's to the order of 30 percent are acceptable for forest insecticide spraying, but in many cases, this level of evenness is difficult to obtain, especially when flying 50 feet above the target. The best overlapped deposit pattern possible (with the lowest CV) can be found by using a calculator or, better still, a computerized method to overlap a previously determined swath pattern. Choosing the optimum lane separation can initially be made visually (i.e., the most even deposit with fewest peaks and valleys) and confirmed by calculating the CV. However, remember that the lane separation that gives the best CV does not always give the required mean deposit density.

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Kuhlman, D.K.; Cress, D.C. 1981. Aerial application handbook for applications. MF-622, Manhattan, KS: Cooperative Extension Service, Kansas State University.

O'Neal H.; Brazelton, R.W. 1984. Aerial application of pesticides. Houston, TX: Shell Chemical Company.

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CHAPTER III.

PESTICIDE FORMULATIONS AND TANK MIXES

1. Proper Mixing and Handling of *Bacillus thuringiensis*

Robert Fusco (for Abbott Labs, Inc., "Dipel")
Temple Bowen (for Novo Laboratories, "Foray")
Jonathan Bryant (for Sandoz Crop Protection Corp., "Thuricide")
Robert Kapinus (for Ecogen, Inc., "Condor")

Dipel: Description and Properties

Robert Fusco

Introduction

All of the Dipel Bacillus thuringiensis var. Kurstaki strain HD-1 formulations registered for use against the gypsy moth are spore/crystal preparations suspended in either aqueous or oil vehicle carriers.

Dipel 6AF and Dipel 8AF are aqueous flowable Bt formulations. Dipel 6L, 8L, and 12L are oil-based emulsifiable suspensions of Bt. Both of the aqueous flowable Dipel formulations and the three Dipel emulsifiable suspension formulations are similar except for potency: Dipel 6AF and Dipel 6L are 48 BIU/gal products, Dipel 8L and 8AF are 64 BIU/gal products, and Dipel 12L is a 96 BIU/gal product. Generally speaking, no unique handling considerations are necessary with the aqueous flowable formulations. They can be sprayed undiluted, as ultra low-volume applications or diluted with water at any dilution ratio. However, as with all pesticides, consult manufacturer's technical bulletins and labels for precise use and handling procedures.

The oil formulations are generally more sophisticated in nature, containing various emulsifiers and other components to insure wettability and sprayability when diluted with water. When tank-mixed with water, they form an emulsion, which is slightly acidic but is noncorrosive to metallic and plastic fittings normally encountered on mixing and application equipment. The acidified suspension also stabilizes the Bt endotoxin against high pH water used in mixing. Final mixture pH should be below 7. Physical properties of Dipel 8L are summarized in the following tabulation:

Appearance	brown-colored liquid
Potency	17,600 IU/mg or 64 BIU/gal
Density	0.92 grams/ml
Weight	7.7-7.8 lbs/gal
Dispersability	miscible with water, diesel fuels, kerosene, agriculture spray oils
Specific gravity	0.91-0.93
Viscosity @ 20°C	350-600 cps

Bulk Handling and Unloading

Upon arrival, Bt material should be recirculated once before unloading or use. This is achieved by pumping the material from the outlet valve back through the open manhole. At least a 5-7.5 hp pump capable of producing a flow rate of 100-120 GPM at 20-30 psi should be used. During this process, the manhole of the tanker must always be open to prevent the collapse of the tanker walls. If unloading the tanker into a holding tank, the tank and lines should be clean and rinsed with diesel. Contact between Bt material and standing water should be avoided, since an invert emulsion can develop if water is present. Material in storage tanks should be recirculated at least once a week to prevent separation and should be recirculated prior to use if it has been sitting for 2 days or more.

When spotting the tanker, the rear of the tanker should be lower than the front if it unloads from the tail. If it unloads from the center, it should be level. The tanker should be placed on solid ground with the front support on solid hardwood planks. If unloading into a compartmentalized tanker, always unload into the rear compartment first, and work toward the front. Reverse the procedure when unloading a compartmentalized tanker (always keep weight over the wheels). This procedure will prevent the tipping of the tanker. All trailers will be equipped with a 3-inch ID male camlock discharge pipe.

Mixing Instructions

All mixing and transfer equipment should be cleaned prior to mixing. Clean in-line strainers and inspect for holes or gaps. Strainer size should be at least 16 mesh, but no finer than 50 mesh. Water to be used in mixing should be clean and filtered of any suspended matter. Water hardness levels should not exceed 700 ppm, and pH of the finished mix should be below 7.

Drums should be rolled prior to use. To prepare the spray mixture, fill the mix tank with the desired quantity of water, and start mechanical agitation to provide moderate circulation, then, add the required amount of Dipel. Drums should be rinsed, and the rinse water should be added to the spray mixture. NEVER ADD DIPEL 6L, 8L, OR 12L TO THE MIX TANK BEFORE INTRODUCING THE DESIRED AMOUNT OF WATER!) A 5-7.5 hp pump capable of producing a flow rate of 100-120 GPM and fitted with a 3-inch, non-collapsible hose is recommended to pump undiluted Dipel. It is not necessary (or recommended) to continually agitate Dipel. Excess agitation or whipping of spray mix or undiluted material may result in increased viscosity, especially of aqueous formulations.

For aqueous tank mixes, Dipel 6L, 8L, or 12L should always be diluted with at least an equal amount of water. Tank mixing Dipel oil formulations with less than an equal amount of water may result in the formation of an invert emulsion. However, this process can be reversed by the addition of enough water to return to at least a 50:50 ratio. Under normal field conditions, tank mix stability is 72-144 hours. However, this will vary depending upon factors such as extent and duration of temperatures reached in the storage tanks, chemical and microbiological purity of mix water used, and others. After long periods of time, Dipel should be recirculated at least once prior to loading in an aircraft.

Typical viscosities of Dipel 6L/8L tank mixes are shown in the following tabulation:

Ratio product: water	Approximate viscosity (centipoise)
60:40	4000
50:50	2000
45:55	1500
40:60	less than 40
25:75	less than 20

Undiluted Dipel 6L/8L Applications. All water must be removed from pumping and spray systems with an oil solvent to spray undiluted applications. The in-line screens and nozzles should be removed and cleaned thoroughly. The spray booms, aircraft spray tank, pumps, and hoses need to be drained to remove all water, and then, the entire pumping system must be flushed with diesel fuel. Screens should be checked to insure that they are no finer than 50 mesh. Thirty (or more) gallons of DIPEL should be added to the spray system. The material should be sprayed out until the system breaks suction to insure lines are completely full. The desired amount of DIPEL can now be loaded into the hopper.

Cold Weather Handling of Dipel Oil Formulations. At low operating temperatures (4-7°C), oil formulations will increase viscosity. When this occurs, agitation or recirculation in the nurse tank or aircraft hopper (during ferry time to spray site) for 5-20 minutes at full pump capacity will increase product temperature several degrees through the combined action of pump impeller friction and shear thinning. When temperatures below 10°C are predicted, store material in a heated hangar or warehouse until use. Storage of the product in large bulk tanks will minimize temperature loss as compared to drum storage. For outdoor storage in either bulk

tanks or 55-gallon drums, solar/thermal blankets (insulation) have been used with some success.

Spray Conditions

Application of Dipel should not be made when rain is forecast within 12hours after treatment or when foliage is wet from dew or precipitation. If rainfall totals more than 1 inch within 48 hours after treatment, a respray should be considered.

Aircraft Spray System Considerations When Using Bt

Particular attention needs to be paid to the aircraft's spray system when applying biological pesticides, particularly those composed of suspended particulate matter such as Bt. The following recommendations, considered to be good operational practices, will provide more accurate application of Bt according to manufacturer's recommendations and should minimize many of the problems inherent in many large operational programs.

- Use of a flow meter such as Crop Hawk, Micronair, Sed, etc., eliminates many application errors and is necessary to make those fine adjustments in flow rate during the application. When using flow meters, always use the correct flow rate cartridge or turbine in accordance with manufacturer's recommendations. The flow rate desired should fall within the middle of the turbine's range of activity.

- Rotary atomizers are recommended for applications below 64 oz./acre.

- With rotary atomizers (i.e., Micronair and Beecomist), the largest orifice/lowest pressure combination should be used to give the desired calibrated delivery. This will minimize load on the pump and allow more uniform flow rates.

- A tachometer may be used to determine the proper setting of rotary atomizers. For accurate results, all tests must be conducted in flight with the atomizers fully loaded with the Bt product.

- An in-line strainer of no finer than 30 mesh should be used.

- Bt manufacturer's recommendations and calibration/characterization trial data should be consulted to determine what type of nozzles to use, nozzle configuration, and general setup of aircraft's spray system.

Careful consideration to the application recommendations given here will improve control of target insects. However, these recommendations are based on limited evaluations of Dipel and are not intended to restrict the product's use or application with respect to diverse types of application equipment.

FORAY 48B -- Mixing Instructions

Temple Bowen

Introduction

FORAY 48B is an aqueous flowable concentrate formulation. The active ingredient, Bacillus thuringiensis Berliner var. kurstaki, has a potency of 48 BIU/gallon and a specific gravity of 1.15 +/- 0.05 (9.5 lb/gal). The material may be applied aerially either undiluted or diluted and from the ground using either a mistblower or a high-volume hydraulic sprayer.

FORAY 48B is especially formulated to be applied aerially. The use of undiluted FORAY 48B avoids the need for mixing. Undiluted applications have the further advantages of 1) applying lower volumes per unit area, 2) avoiding tank mix shelf life limits, 3) improving adherence to target foliage, 4) avoiding errors in mixing ratios, 5) providing greater aircraft productivity, and 6) reducing ground support requirements. Stickers are not recommended for use with undiluted FORAY 48B. If stickers are used, compatibility of the specific sticker must be checked by adding the recommended ratio of sticker to a small (1 or 2 gallons) amount of FORAY 48B[4]. The test mix should be stirred/agitated vigorously and then allowed to stand for 1/2-1 hour. After another agitation, the mix should be checked for any signs of incompatibility such as clumping, formation of precipitates, increased viscosity, separation, etc. Undiluted FORAY 48B may be added to any standard spray system that has been rinsed with water. Residual quantities of water in the lines, valves, tank sumps, or diluted oil-based emulsifiable suspensions will have no adverse effect on the handling ease of FORAY 48B. Do not add FORAY 48B to a system that has residual amounts of undiluted oil-based emulsifiable suspensions since the emulsifiable suspension will invert and cause the system to clog. FORAY 48B acts as a spray system cleanser. If a spray system has some particles adhered to the inside of the pipes, booms, etc., these particles are likely to be flushed out of the system during the first two or three tank loads.

FORAY 48B may be diluted with any amount of water. The mixing sequence is not critical. The water can be added to FORAY, the FORAY to water, or both loaded simultaneously without concern for the creation of any adverse tank mix characteristics. This advantage can be helpful under operational conditions. For instance, mixing can be done directly in the aircraft hopper so long as there is recirculation in the hopper. One system that has been successfully used is to have two suctions attached to a "Y" on the intake side of the pump. One suction leads to the water source, the other leads to the FORAY source, and both intake lines are equipped with shutoff valves at the "Y". There is only one loading hose. The loading hose is connected to the aircraft. The pump is started, and the FORAY "Y" is opened. After the proper amount of FORAY is metered in, the FORAY line is shut off, the water line is opened, and the proper amount of water is pumped in. This system has the advantage of 1) no premixing, 2) no chance of leftover mixed material, 3) pump and loading hose rinsed after each load, and 4) pump and loading hose always filled with water after each loading operation.

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[4] Bond sticker is not compatible with FORAY 48B. Other stickers that have been tested and found to be physically compatible with FORAY 48B include Plyac, Nufilm 17, Complex 500, and Chevron.

Stickers may be used with diluted tank mixes of FORAY 48B and may enhance resistance to washoff. If stickers are used, they should either be added to the water or added to the final tank mix. They should not be added to the undiluted FORAY. After adding the sticker, sufficient agitation/recirculation should be done to assure a homogeneous tank mix of FORAY, water, and sticker. As mentioned before, compatibility of the specific sticker must be established before using any sticker with FORAY 48B.

If the original containers of FORAY 48B have been standing for an extended period, some shaking, agitation, or stirring may be required to resuspend the material and provide a homogeneous product. In most cases, if the entire jug or drum is to be used at once, this will not be necessary. Empty the first container and visually check the bottom of it. If no significant residual remains, it means the entire contents have been transferred to the spray tank. Subsequent spray tank agitation or recirculation will assure homogeneous spray tank material.

As with all pesticides, read the label carefully, and follow the directions. For further information on special handling techniques, compatibility, recommended volumes/dosages, recommended atomization parameters, etc., call the appropriate technical representative. For NOVO/FORAY, this would be Temple Bowen at 1-800-678-NOVO or 1-203-790-2632.

How to Use Thuricide Products

Jon Bryant

Introduction

Sandoz forestry products are made from *Bacillus thuringiensis* fermented and formulated at the dedicated Sandoz facilities in Wasco, California. Currently, four formulations are registered in all major states with forestry programs: Thuricide 32LV, 48LV, and 64LV (32, 48 and 64 BIU/gallon products, respectively, and SAN-415 32LV in a 32 BIU/gallon product.

All products are low viscosity aqueous formulations designed for optimum mixing and handling characteristics and easy application through a wide range of aerial and ground atomizers. All have been successfully applied diluted with water, when enhanced coverage is required, or as undiluted sprays, when advantages of low volume applications are required.

The Bt used in SAN 415 32LV is an enhanced strain of the common variety *kurstaki*, originally isolated by the US Forest Service for its 2.5-3 fold increased activity against gypsy moth and spruce budworm. However, the formulated product does not require any special use directions compared to other Thuricide products.

Bt Use Directions

Most deliveries are made in 5000 gallon road tankers, although 53 gallon plastic drums are used for small operations. When positioning or spotting the tanker, take into consideration that 24 hour access may be required for authorized personnel, safety of the location and restricted access to prohibit tampering. Also, consider the physical placement for ease of aircraft operation, and locale relative to spray blocks and water source. Clear access for nurse tankers or aircraft should be assured.

Bulk tankers must be located on firm, level ground or concrete aprons; center unloading tankers should be level, rear unloading tankers should incline slightly to the rear to ensure complete emptying. Always unload from the front section first, finishing with the compartment over the wheels.

Pumps located next to the tankers should have adequate capacity to supply recirculation and rapidly fill nurse tanks and aircraft; capacity of at least 100 gallons/minute is suggested. Recirculation for 45-60 minutes should be made prior to unloading by drawing material from the main outlet and recirculating through the top of the tank; ensure each compartment is freely vented. Each compartment of the tanker will need separate agitation prior to use.

In-line strainers should be used before the pump with a 30-mesh screen. Particular attention should be paid to filtering water. Check and clean all equipment prior to use and recheck periodically through the program to ensure integrity.

Sandoz formulations are low viscosity and will thicken slightly at low temperature, but will not adversely affect operation. Overnight freezing or high day-time temperatures will not affect product quality of material in the bulk tank for short storage periods. Be careful leaving aqueous formulations in the spray system under extreme cold periods.

Once a product is mixed with water, it may be left for up to 72 hours providing it is agitated prior to use.

The addition of a registered sticker to undiluted applications may enhance rainfasteners of Bt's when rain occurs following application. If heavy rain occurs

soon after application, retreatment may be required. Consult Forest Service recommendations for guidelines. While no adverse effects have been noted for Sandoz formulations, it is advisable to mix a small (1 pint) glass jar with representative proportions of Bt, water and sticker prior to full scale operation. Inspect the contents after 1 hour for gross formulation changes (sludging, separation of suspended components, etc.).

Application Equipment

Sandoz formulations have been field tested under a wide range of conditions using rotary and hydraulic atomizers from fixed- and rotary-wing aircraft. Under extreme conditions (high flow rates per atomizer and low aircraft speed), it is advisable to check droplet size during a characterization test prior to field use. Atomization giving high volumes of droplets with diameters greater than 250 μm should be avoided.

Using Condor OF

Robert Kapinus

Introduction

Condor® OF Bt forestry product is available from Ecogen, Inc. as an oil flowable (OF). It is an emulsified concentrate of Bt fermentation product that will readily disperse when added to a water diluent. The concentration of delta endotoxin protein per gallon is 7.5 percent.

Condor OF is a highly selective insecticide for use against gypsy moth larvae. Larvae must consume deposits of Condor OF to be affected. Use of Condor in a manner inconsistent with its labeling would constitute a violation of Federal law. Mixers, loaders, and ground applicators must wear goggles and a dust mask. Always follow these directions:

- Apply before extensive foliar damage has occurred.

- Spray thoroughly, as complete coverage is essential to good insect control.

- When insect infestations are heavy, use the higher label rates or administer a second application, 7-10 days after the first.

- For improved durability of spray deposits, use an approved sticker.

- Treat when larvae are young (early instars) and are actively feeding on foliage.

- When using a single application for insect control, apply when egg hatch is essentially complete. Gypsy moth larvae will be in the first or second instars.

Application Instructions

Condor OF may be applied with aerial equipment using quantities of water sufficient to provide thorough coverage of infested plants. To obtain a suitable mixture with water, fill the mix tank or spray tank with the desired quantity of water, then add Condor OF. Condor OF should be mixed well and never added before introducing water into the tank. If a sticker is to be used, add it after adding Condor OF. Mechanical or hydraulic agitation may be used. Maintain suspension during loading and spraying. Do not mix more Condor OF than can be used in a 24-hour period. (CAUTION: Rinse and flush spray equipment thoroughly following each use. Do not contaminate water when disposing of equipment wash water.

User Precautions

Local conditions may affect the use of Condor OF. Consult your State agricultural extension specialist for specific recommendations related to local crop protection problems. Ecogen makes no warranty, express or implied, including the warranties of commercially acceptable quality and/or fitness for any particular purpose concerning this material, other than those indicated on the label. The user assumes all risks of use, storage, or handling not in strict accordance with the accompanying directions.

Application Rate

Condor OF for trees should be applied at the following rates:

Crop	Pest	Pints/acre (aerial application)[a]
Forest, shade trees and shrubs	Gypsy moth	2.0 to 2.5

[a] For aerial applications, use up to 2 gallons of water per acre, depending upon type and density of stand. Best results are obtained with spray systems that deliver droplet sizes below 200 µm in diameter. For diluted applications, Condor OF should always be mixed with at least an equal volume of water.

2. SPRAY STICKERS

Win McLane

Introduction

Aerial application of pesticides to suppress and/or eradicate gypsy moth infestations can be costly and time-consuming. A number of important items must be considered and decided upon before an aerial spray project can take place. The question of sticker use is one of the major items that should be addressed in the early stages of planning any gypsy moth spray program.

The addition of a small amount of sticker to Bt can often make the difference between good and poor results. Some registered gypsy moth spray materials are very susceptible to small amounts of rainfall following treatment. After appropriating considerable money and staff hours to a spray project, one certainly cannot afford to have the spray end up on the ground. Most gypsy moth spray is applied to oak foliage, which is very smooth and waxy and more susceptible to washoff than other types of foliage.

To demonstrate the effectiveness of individual stickers for the different insecticides used in gypsy moth control, details of experimental results (McLane 1975-86) are presented in the tables that follow.

Dimilin Application

When Dimilin is being sprayed, it is not necessary to add sticker. All registered Dimilin formulations adhere very well to oak foliage. Laboratory data indicate that there should be minimal washoff if Dimilin is applied up to 2 hours before a moderate (.25-.50 inches) rainfall. (Table III-2a)

Table III-2a--Mortality of second-stage gypsy moth larvae following 7-days' exposure to red oak foliage treated with three Dimilin formulations and subjected to rainfall after 2 hours.

Formulation	Rainfall (Inches)	Mortality (Percent)
Dimilin 25 W	-	98
	1.0	98
	2.0	100
	3.0	100
Dimilin 2F	-	96
	1.0	98
	2.0	99
	3.0	100
Dimilin 4L	-	99
	1.0	100
	2.0	98
	3.0	100
Check	-	0
	3.0	4

Orthene Application

If Orthene is used for gypsy moth control, a sticker is needed. A sticker such as NuFilm 17 should be added to the final tank mix at a rate of 3 percent by volume (Table III-2b).

Table III-2b--Mortality of second-stage gypsy moth larvae following 4 days'exposure to red oak seedlings treated with 1.0 lbs AI/gallon/acre of Orthene 75S with and without sticker and subjected to 2 inches of rainfall.

Sticker at 3%	Rainfall (Inches)	Mortality (Percent)
No Sticker	--	97
No Sticker	2	22
NuFilm 17	2	95
Chevron	2	47
PLYAC	2	28
Check	--	0
Check	2	0

Sevin Application

A sticker such as NuFilm 17 should be used with Sevin 80S or Sevin 50W when being applied by ground equipment. The material can be applied to the final mix at a rate of 2 percent or less by volume. Other Sevin formulations, such as Sevin 4F, Sevin 4-oil, and Sevin XLR do not require a sticker (Table III-2c).

Table III-2c--Mortality of second-stage gypsy moth larvae following 4 days' exposure to red oak seedlings treated with four Sevin formulations and subjected to rainfall after 2 hours.

Sevin formulation	Sticker	Rainfall (Inches)	Mortality (Percent)
Sevin 80 S - 50W	-	-	99
Sevin 80 S - 50W	-	1.0	18
Sevin 80 S - 50W	NuFilm 17	1.0	78
Sevin XLR	NuFilm 17	1.0	99
Sevin 4 Oil	-	1.0	100
Sevin 4F (Agway)	-	1.0	84
Check	-	-	0
Check	-	1.0	0

Bt Application

When using any formulation of Bt for gypsy moth control, it is recommended that a sticker such as Bond be added to the final tank mix (Warning: Bond sticker should not be added to formulation of FORAY, instead use Plyac sticker.). As a result of testing numerous Bt formulations in the laboratory over the past 20 years, it has been determined that most formulations wash off oak foliage when exposed to small

amounts of rainfall. Always use a sticker with Bt, even if rain is not forcasted for the post-spray days (Table III-2d).

Table III-2d--Mortality of second-stage gypsy moth larvae following 4 days' exposure to red oak seedlings treated with Bt formulations and subjected to rainfall after 2 hours.

Formulation	Dosage/rate	Rainfall (Inches)	Sticker	Mortality (Percent)
Dipel 8L (oil)	12 BIU/96oz/acre	--	--	89
Dipel 8L (oil)	12 BIU/96oz/acre	.25	--	26
Dipel 8L (oil)	12 BIU/96oz/acre	.25	2% Bond	78
Thuricide 48 LV	12 BIU/96oz/acre	--	--	74
Thuricide 48 LV	12 BIU/96oz/acre	.25	--	49
Thuricide 48 LV	12 BIU/96oz/acre	.50	--	40
Thuricide 48 LV	12 BIU/96oz/acre	.25	1% Bond	83
Thuricide 48 LV	12 BIU/96oz/acre	.50	1% Bond	90
Thuricide 48 LV	12 BIU/96oz/acre	.25	3% Bond	97
Thuricide 48 LV	12 BIU/96oz/acre	.50	3% Bond	100
Check	--	--	--	0
Check	--	.5	--	0

Mixing Procedure

When stickers are used, they should be added to the formulation last or added to the water before the active material as the mix is being agitated in the nurse tank. It is good operational procedure to screen all stickers through a 50-mesh screen as they enter the nurse tank. Once added to the nurse tank, agitation should continue for a 10-minute period before the aircraft is loaded. If excessive foaming occurs, it may be necessary to reduce the degree of agitation. Check in-line screens occasionally for sticker buildup and clogging. If material is not passing smoothly from the nurse tank to the aircraft, it is likely that an in-line screen is clogged. Partial containers of sticker should be covered securely and stored in a protected area until used. If covers are left off, a hard coating may form on the surface and result in clogged screens and/or nozzles.

Several stickers, when used with Bt, have been found to create removal problems on cars and other outdoor items. Property owners should be advised to cover vehicles and other outside objects or place them inside during spraying. If this is not possible, then, the item should be washed as soon as possible after being sprayed. In most cases, a good detergent and hot water will remove any spray deposit.

Sources of Material

The companies listed below market products for gypsy moth control and provide information on their use:

Product	Source
Dimilin	Uniroyal Chemical Specialty Products World Headquarters Middlebury, CT 06749 (203) 573-3888

Bacillus thuringiensis Dipel	Abbott Laboratories Chemical and Agriculture Products Division North Chicago, IL 60064 (800) 323-9597
Bacillus thuringiensis Thuricide	Zoecon Corp. A Sandoz Company Crop Protection Division P.O. Box 1095 Palo Alto, CA 94303 (415) 857-1130
Bacillus thuringiensis Foray	NOVO Laboratories, Inc. NOVO Biokontrol 33 Turner Rd. Danbury, CT 06810-5101 (203) 790-2600
Bacillus thuringiensis Condor	Ecogen, Inc. 2005 Cabot Boulevard, West Langhorne, PA 19047-1810 (215) 757-1590
Sevin	Rhone-Poulenc, Inc. P.O. Box 125 Monmouth Junction, NJ 08852 (201) 297-0100
Orthene	Chevron Chemical Company Agricultural Chemical Division 575 Market St. San Francisco, CA 94105 (415) 894-7800
Bond	Loveland Industries, Inc. P.O. Box 906 Loveland, CO 80537 (303) 667-6620
Plyac	Hopkins Agricultural Products Division P.O. Box 7532 537 Atlas Ave. Madison, WI 53707 (608) 221-0621
NuFilm 17	Miller Chemical and Fertilizer Corp. P.O. Box 333 Hanover, PA 17331 (717) 632-8921

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3. PROPER HANDLING OF DIMILIN

Win McLane

Introduction

Dimilin (Diflubenzuron), an insect growth regulator, was registered by the Environmental Protection Agency in April 1976 for control of gypsy moth in the United States. Dimilin affects chitin formation and, because of this mode of action, only immature stages are affected. Without chitin, internal pressure from larval growth causes the weakened exoskeleton to rupture, resulting in the insect's death before it reaches the next instar. Dimilin does not kill gypsy moth larvae immediately but will reduce populations within 3-5 days.

Application Methods

Dimilin 25W is registered for applications of 2 to 4 ounces per acre for gypsy moth control. Most often, it is applied at .03 pounds actual ingredient (2 ounces of 25W) per acre in 1 gallon of water. No sticker or other additives need to be mixed with the formulation. The formulation is normally applied through conventional flat fan nozzles from fixed- or rotary-wing aircraft. Aerial treatments can be made from both small single engine or large multiengine aircraft. Applications of Dimilin can be made with Micronair atomizers. However, atomizer blade angles should be set to give low rotation speeds (2,000-4,000 rpm) to avoid potential problems of evaporation of small drops. The material can be applied with ground equipment such as mistblowers or hydraulic sprayers. Sufficient water volume should be used to achieve uniform coverage of foliage.

Spray Mix Preparation

As the spray is being readied for use, a sufficient amount of water should be added to the nurse tank and light agitation started. As agitation continues, the proper amount of Dimilin 25W should be slowly added to the tank, with the operator standing upwind. Proper clothing and face gear should be worn when handling Dimilin.

In most cases, the material can be added rapidly. However, it is possible that clumping and/or clogging may occur. Once all active material has been added, the mix can be topped off with water to the desired level. Light agitation should continue for at least 10 minutes before loading the aircraft and also continue in the nurse tank as the material is being loaded into the aircraft. If some material remains in the nurse tank, agitation can continue until the aircraft returns, and the tank is emptied. If the material is not agitated between loads, the mix should receive light to medium mixing for 10 minutes before the aircraft can be loaded again. It should be borne in mind that excessive agitation can cause heavy foaming of the material. If this occurs, the degree of agitation must be lessened. Use a defoamer only as a last resort. However, remember that light agitation must be maintained. If, however, the mix is held overnight or for a number of days in the nurse tank, strong agitation will be needed to get all material back into suspension. All nurse tanks and aircraft must have good agitation systems when using Dimilin 25W. The material must be lightly agitated in the aircraft on the way to the spray plot and, if possible, during application.

Check the nozzle and in-line screens periodically for buildup of foreign matter that may obstruct the flow and cause a drop in pressure. Obstruction will normally occur first on nozzle screens at the ends of the boom.

CHAPTER IV.

AERIAL SPRAYING: METHODOLOGY AND PRACTICE

1. A Guide to Weather and Gypsy Moth Operations in the East

Dan Twardus

Introduction

At the time of a spray application, it is important to recognize that weather conditions have a direct effect upon spray deposit and, hence, spray effectiveness. Five conditions to be aware of are:

- Low humidity and high temperatures causing evaporation of volatile components of the spray.
- Insufficient wind or turbulence resulting in a hanging spray cloud.
- Inversion layer resulting in poor settling of smaller drops.
- Thermals caused by the heating of an unstable air mass.
- Rain or wet foliage causing spray runoff.

Low Humidity, High Temperatures

If an insecticide formulation contains evaporative components or is diluted in an evaporative carrier such as water, then the size of droplets reaching the target and their behavior will vary with time of flight and be influenced by temperature and humidity (Parkin 1987). When spraying a forest, evaporation is a problem more so than in agricultural spraying because the aircraft's height above the forest canopy is at least 50 feet. According to calculations made by Ciba-Geigy, at 85°F a water-based droplet 100 µm is size can evaporate by 40 percent after falling only two feet, whereas, an oil-based droplet of the same size can lose only 28 percent of its weight after 30 feet.

Most insecticide formulations contain additives to impede evaporation. However, among insecticide formulations, a variation in evaporation rate can be expected. Sundaram et al. (1987), have demonstrated different evaporation rates for three water-based formulations, each sprayed with VMD's less than 100 µm:

Future XLV	(1.65 percent/minute)
Thuricide 48 LV	(1.75 percent/minute)
Dimilin 25 W	(2.45 percent/minute).

Note the evaporation rate of Dimilin is 40 percent higher compared to the two Bt products.

Dennison and Wedding (1982) concluded that for water-based formulations the greatest influence on evaporation rate was initial droplet size (the larger the initial droplet, the less the influence of evaporation), and relative humidity the next most important influence. Oil-based formulations showed a negligible effect from changes in relative humidity. Ironically, for both water- and oil-based formulations, the influence of temperature was considered small in comparison to other factors. One of those other factors is surface tension of the droplet. Surface tension increases the resistance to small droplet formation and it's the small droplets that have the highest evaporation rates (R. Ekblad, USDA, personal communication). Surface tension is a function of the formulation.

For gypsy moth aerial spray operations in the eastern United States, the temperature/humidity thresholds at which spraying should be intensively monitored are:

- Aqueous formulations - temperatures in excess of 80°F and/or relative humidity less than 60 percent.
- Oil-based formulations with water added - temperatures in excess of 85°F and/or relative humidity less than 40 percent.

The 60 percent relative humidity rule for aqueous formulations is based upon the observation that the rate of change of an aqueous formulation is dramatic below 60 percent relative humidity (Spillman 1984). These thresholds are particularly important

when using small droplet sizes (less than 115 μm). This is because evaporation reduces the size of these small droplets far more rapidly than it does larger ones.

Temperature and humidity should be measured at the spray block or in a geographically similar area close to the block. Measurements should be made at least six feet above the ground. (CAUTION: The relative humidity at crown level or aircraft height will usually be less than at six feet above the ground.) Relative humidity is the amount of water vapor in the air relative to the maximum amount the air could hold if it were saturated at the same temperature. It is always expressed as a percent. The psychrometer or sling psychrometer is the most accurate method for determining relative humidity. A sling psychrometer must be spun for 90 seconds to arrive at an accurate reading of depression of the wet bulb. The wet bulb reading is used in conjunction with dry bulb reading to estimate relative humidity.

Insufficient Wind or Turbulence

Wind provides energy to move a spray cloud and should be used to help target spray deposition. For this reason, the best wind conditions are organized in one general direction and steady. Ideal wind conditions range from 3-10 mph, without gusts (Jack Barry, Win McLane, USDA, personal communications). Winds less than 3 mph are usually variable and, hence, less dependable.

Smaller spray droplet sizes (20-100 μm), because of their lower fall velocities, are greatly affected by wind. Wind distributes droplets over and around the foliage by turbulent diffusion. It is the essential mechanism whereby droplets are spread out after they are out of influence of the aircraft wake. Without wind, turbulent mixing will be negligible and the droplets will stay in a relatively dense cloud falling very slowly and moving with the predominant air flow. Spraying in near-calm conditions is common and successful in agricultural spraying when applying large (>250 μm) droplets. Agricultural aircraft also fly close to the target (5-10 feet), with downwash or wake causing penetration of the spray deposit. Most forest sprays, however, are released too high above the canopy to be effectively distributed by wake effect alone. For this reason, it is advantageous to have some wind energy and turbulent forces to help move the spray cloud along and into the canopy.

When a spray cloud reaches the top of the canopy, its penetration into the canopy is a function of air turbulence and sedimentation of the droplets. Turbulent eddies within the canopy are important because they carry the small droplets into the foliage (Fig. IV-1b). The sedimentation speeds (that is, droplets falling by gravity alone) of 30- and 50-μm drops are about .06 and .15 mph, respectively. In a forest canopy, windspeeds of 3-10 mph can greatly augment dispersion of droplets.

When spraying in near calm conditions, droplet density is primarily controlled by aircraft wake effect and droplet sedimentation. The aircraft should fly as close to the target as safety permits (usually 50 feet). Downwash decreases with increasing aircraft speed; therefore, the aircraft should also fly somewhat slower. If these calm conditions will predominate during spraying, the aircraft should be recalibrated for the slower air speed.

In general, near calm conditions should be avoided. The basic concept is to cover large amounts of foliage with a minimum amount of insecticide. It is generally recognized that large drops (larger than 100 μm) contain over 50 percent of the spray mass (Crabbe et al. 1982). Consequently, an attempt should be made to use smaller droplets released into a 3-10 mph steady wind. The turbulence associated with these winds will aid in distributing the droplets throughout the canopy.

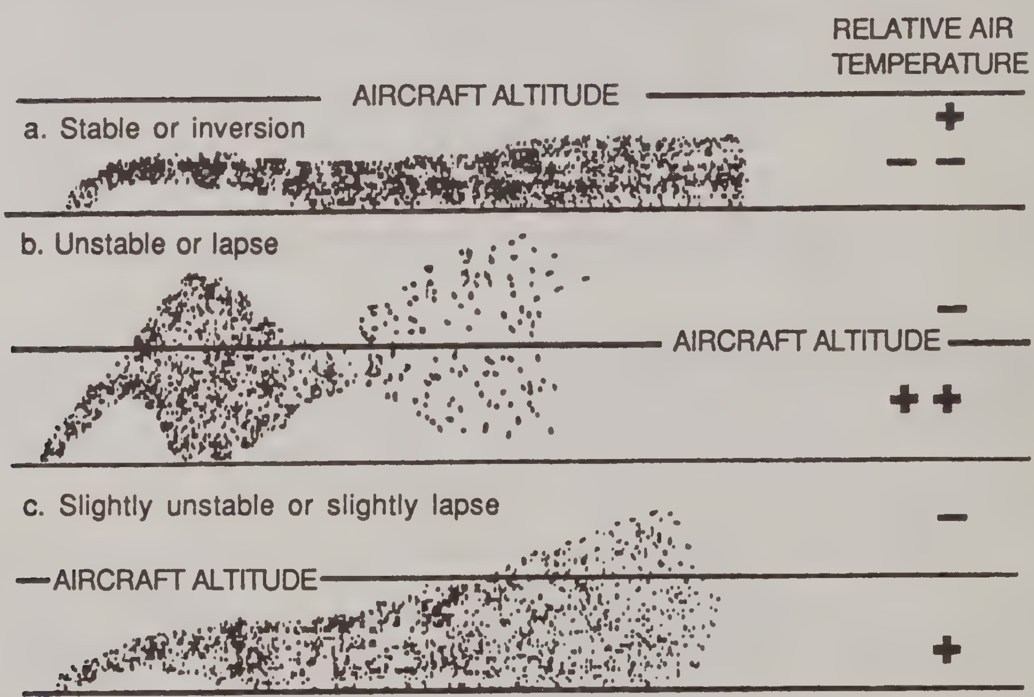

Figure IV-1a-c. Smoke plume diffusion under (a) stable, inversion or calm condition, (b) unstable condition, and (c) slightly unstable (plus = warmer air, minus = cooler air). (Source: Handbook on Aerial Application of Herbicides, 1983).

At the other extreme, high winds (over 10 mph) can result in increased drift. Windspeed measurements should be taken only to insure that they fall within the acceptable operational range of 1-10 mph. As with temperature and humidity, windspeeds outside these limits should serve as caution zones. Windspeeds above 10 mph are not necessarily detrimental to effective spray deposit; however, above this threshold spray deposit should be closely monitored for off-target movement. Of particular importance at higher windspeeds is the assurance that gusting winds will not cause patchiness in the spray deposit.

Wind direction should also be observed to insure that it will not result in spray drift outside the spray area. Wind direction should be used to help target the spray cloud, with aircraft flying perpendicular to its direction. Spraying perpendicular to the wind direction uses the energy of the wind to help spread the cloud across and into the target, resulting in a more even application as successive swath patterns overlap.

Windspeed and direction estimates should be made as close to the spray area as possible. Cup anemometers provide a reliable method of estimating windspeed. They should be used in an opening at least four to five tree-heights across and at least six feet above ground cover. The simplified Beaufort wind scale (Table IV-1a) can be used as a guide when an anemometer is not available. In general, windspeed increases with height above open ground level. For a windspeed measured at 6-10 feet above the ground, add 48 percent to more closely reflect windspeeds in the canopy (Furman et al. 1984).

Table IV-1a. Simplified Beaufort windspeed scale.[a]

Beaufort number	Wind description	Visible sign	Approximate mph
0	Calm	Smoke rises vertically	0-1/2
1	Light air	Direction is shown by smoke drift; barely moves tree leaves	1-3
2	Light breeze	Leaves rustle, wind felt on face; small twigs move	4-7
3	Gentle breeze	Leaves and small twigs in constant motion; blows up dry leaves from ground	8-12
4	Moderate breeze	Small branches move; raises dust and loose paper	13-18
5	Fresh breeze	Large branches and small trees in leaf begin to sway	19-24

[a] Schaefer, V.J. and J. Day. 1981. A Field Guide to the Atmosphere. Boston, MA, Houghton Mifflin Co., 359 pp.

Inversion Layers

Droplet deposition on the forest canopy occurs mainly by impaction and sedimentation. A common reason for lack of deposition of small droplets is the existence of a temperature inversion. An inversion layer is a band of air which underlies a warmer air mass. In flat areas, this is usually caused by radiation or radiational cooling of the ground during cloud-free nights, and in mountainous areas by drainage of cool air into lower elevations. If small drops are sprayed above this layer, they will hang suspended and tend to move horizontally with the airmass. In the inversion region, turbulence is also lacking as inversions are usually stable calm conditions (Fig. IV-1a). Large droplets fall easily, and are not moved out of the spray area. Be aware, however, that the small droplets can drift a long way and will not be substantially dispersed under such conditions.

Maximum temperature inversions usually occur when a high daytime ground temperature is followed by radiation cooling to cloudless sky (Akesson and Yates 1974). The cold-sky radiation cooling produces an inversion which starts in early evening, continues through the night reaching a peak in the early morning, and is the usual pattern for inversion establishment in relatively flat areas (Akesson and Yates 1974). Spraying that begins too early (at daylight) may be less likely to distribute small droplets within the canopy simply because of inversion conditions and lack of turbulent eddies. Spraying in a cloudless evening, after a sunny day, may also show poor small droplet distribution in the canopy due to the reestablishment of a temperature inversion. In both cases, the wake of the aircraft is the principal energy source distributing small droplets.

With overcast skies, temperature gradients above and within a forest are too small to influence droplet dispersal within a canopy. Under clear skies, temperature gradients are greater. Generally, temperature inversions above the forest crown disappear by 8:00 a.m., and within the canopy by 9:00 a.m. By 7:00 p.m. on clear days, inversions can again be established in the canopy.

One of the best indications of an inversion is smoke rising a short distance vertically, then hanging, forming a horizontal layer (Fig. IV-1a). Figure IV-1c represents ideal conditions for spraying. While spraying, another common indication of a hanging spray cloud is droplet deposit on the windshield and fuselage of the aircraft. On the ground, "cool spots" in the low areas along the roadway may be detected. Typically occurring conditions to expect an inversion are:

• A high pressure area has been centered over the region for at least one day.
• Warm days followed by clear, cool nights.
• Visibility shows a marked decrease without the presence of precipitation.

There are certain unstable air conditions which result in air parcels near the earth, warming and rising, then being replaced by cool air from above. These form vertical eddies bringing cool air down from aloft and carrying warm air away from the ground. These eddies provide one of the ways by which the solar energy that is absorbed at the ground is carried aloft (Longley 1970). This process becomes very noticeable in spring and summer, particularly in dry areas. Pilots know these vertical eddies as thermal updrafts that cause a bumpy ride as the aircraft passes through.

A spray released into these thermal updrafts will be entrapped in a rising bubble of air and will not reach the canopy. The best ways to recognize thermal updrafts is through pilot reports, rising columns of smoke, dust devils, and usually the appearance of fair weather cumulus clouds (Karl Mierzejewski, Penn State Univ., personal communication). Fair-weather cumulus clouds are white and have flat bases with rounded tops resembling cauliflower. This is a cloud formation that usually appears in late morning or early afternoon and is produced by upward rising currents of air. The clear areas between the clouds are areas in which the predominant air motion is downward.

Spraying should be stopped whenever thermal updraft conditions appear. Use the appearance of fair-weather cumulus clouds as the indication that thermal updrafts are established.

Rainfall, Wet Foliage, and Spray Deposition

The precise effect of rain upon spray deposition has not been well documented for forestry applications. However, rainfall is known to have an adverse effect on spray deposit retention and residual levels of *Bacillus thuringiensis* (Bt) on foliage. Therefore, a spray sticker is recommended when using diluted Bt (Win McLane, APHIS, personal communication). Undiluted applications of some formulations that contain stickers may not require additional sticker to be added. Generally, the manufacturer of Dimilin recommends that spraying should not take place when rain is imminent (definite rain is less than one mile away, or there is more than a 75 percent chance) or when foliage is dripping wet. After the spray material is dry (several hours), rain will have less of an affect on the deposited material (Paul Bohne, Uniroyal, personal communication).

For Bt, rainfall is generally considered a problem when it is in excess of 0.1 inches and occurs within several hours before or after the spray application. Rain before the application may leave foliage too wet for Bt to stick to it or it may adversely alter surface tension of the leaf or drop. Foliage conditions should be checked by walking through the planned treatment area. If the foliage is wet or if water can be shaken from it, spraying should be delayed until conditions are drier.

Weather observers should observe and note rainfall in treatment areas. The easiest and most reliable method of estimating amount of rainfall is to place rain gauges in representative areas within the general spray area.

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2. INSECT AND FOLIAGE DEVELOPMENT

Normand R. Dubois

Introduction

Timing for the aerial application of an insecticide including Dimilin (diflubenzuron), *Bacillus thuringiensis* (Bt), and Gypchek (the NPV virus), is in large part dictated by the larval hatch and development rates and to a lesser extent by the rate of foliage development. Since both of these variables are very much influenced by geographical location and by short- and longterm weather conditions, one cannot predict a specific spray date several months in advance. Generally, however, aerial application could begin as early as late April to the first 2 weeks of May in some southeastern areas or could be delayed until early June in northeastern interior and higher elevation areas. Therefore, three factors have to concern the applicator when considering the timing of aerial application: 1) The insecticide itself, 2) foliage, and 3) larval hatch and development rates.

The Insecticide

Dimilin is an insect growth regulator (IGR) that inhibits the synthesis of chitin in the larvae. Unlike the case with conventional chemical insecticides, death from Dimilin intoxication is not immediate, rather, the insect usually dies while attempting to molt into the next instar. Because of this unique intoxication mechanism, Dimilin has little or no effect on adults. Its effectiveness is inversely related to larval size and development; that is, younger, smaller larvae are more susceptible to a given dose than larger, older ones. Thus, Dimilin should be applied when larvae are in their I-III instar, preferably before the foliage is fully expanded.

Bt has several limitations an applicator should be aware of: 1) It must be ingested; this implies that it cannot be applied until sufficient foliage surface is available to deposit an effective dose, and larvae are sufficiently developed and actively feeding on that foliage; 2) Bt has a limited period of residual activity; once applied, the insecticidal components of Bt can begin to deteriorate due primarily to the germicidal effect of the U.V. part of the spectrum of the sun. Present formulations of Bt will resist this deteriorating effect and retain their insecticidal potency for a period of 7-14 days or longer. Washoff by rain can also be avoided by use of an appropriate sticker in the spray mixture.

Foliage Feeding Procedures

Gypsy moth feed preferentially on oak foliage. However, alder, paper and gray birch, bigtooth and quaking aspen, and several other tree species are also considered most preferred as food for gypsy moth. A breakdown of food preference classes is readily available from the USDA (Houston and Valentine 1985). Generally, white oak are the last of the host species present in gypsy moth infestations to experience budbreak and leaf expansion. Budbreak on preferred host generally occurs around the latter part of April. A recent study on the effect of temperature (degree-days) on budbreak and leaf growth (Valentine 1983) in gypsy moth-susceptible trees showed that April 15 (Julian date 105) is a good starting point to count the degree-days to estimate percent budbreak and leaf growth. On the average, budbreak begins on white oaks after 144 (+ 31) degree days (+ SD) from day 105, whereas, on red maple, it begins after 86 (+ 28) degree-days from day 105. Budbreak in other tree species tends to fall between these two extremes. Leaf growth in black oaks tends to be the slowest followed by sugar maple and white oaks. Of the species examined, American beech and red maple tend to have the shortest growth period. When foliage on white oaks is 40-50 percent expanded, foliage on other tree species is usually 60-90 percent expanded, and most of the larval population is by then actively feeding. Application of Bt at this stage of foliage development rather than earlier reduces the dilution effect of the dose deposited on the leaf surface that results from leaf expansion.

Gypsy Moth Larvae

Larval hatch usually occurs around budbreak or shortly thereafter. Because of dispersal activities by first instar larvae, feeding on foliage is minimal, and when there is feeding, gypsy moth larvae are very sensitive to the presence of Bt and may hesitate from feeding on Bt contaminated foliage. Older larvae (i.e., 2nd and 3rd instars) are

voracious feeders and will ingest lethal doses of Bt from contaminated foliage. Larval susceptibility to Bt is, in part, biomass related, and 2nd instar larvae are three to five times more susceptible to a fixed dose than larger older larvae. Therefore, application should be made when most of the larvae are second instar. Presently, there is no simple way to predict, from the day of hatch, when larvae will have matured to second instar (II). Larval developmental rates are particularly sensitive to temperature and less so to foliage type and age and to geographical location. Casagrande and his colleagues (1987) have published a model to estimate gypsy moth development rates based on exposure at constant temperatures that could be used to estimate an approximate spray date. Roughly at mean temperatures of 52°F (11°C), 56°F (13°C), or 64°F (18°C), newly hatched larvae will have matured to II in 38, 27, and 16 days, respectively. One could also use the reciprocal of equation (1) in that publication and quickly calculate an approximate date; i.e.,

$$(1)\quad \#\text{ days to II} = \frac{1+e^{3.783-.1895T}}{0.1712}$$

where T is the mean temperature (in°C and available from local weather reports). Needless to say, the estimate has to be revised as daily mean temperatures change. Nonetheless, the procedure could give an applicator as much as a week's lead time and allow for final preparations prior to spray application.

The ability to identify the proportion of early stage larvae (1st, 2nd, 3rd) present in the area proposed for treatment is critical in estimating application timing for biological insecticides. Onken and Soctomah (1987) suggest head capsule width measurements to distinguish among the early stage larvae and generally categorize larvae as first stage less than 0.80 mm, second stage between 0.80 and 1.35 mm, and third stage greater than 1.35 mm. Also, they showed a high linear correlation for early stage larval distribution between larvae in the overstory and the understory (i.e., understory vegetation sampled was dependent upon the presence of larvae). Consideration to differences in elevation and aspect within the proposed spray area will have some influence on prolonged egg hatch or larval development and the subsequent accuracy of any estimate of larval development.

In practice, larval population development rates and foliage expansion are rarely in synchrony, and an applicator has to compromise and spray under less than ideal conditions. Generally, application timing should be dictated by considering larval development rates first, followed by foliage expansion rates. Listed below are several larval and foliage conditions usually encountered and the action that should be taken under these conditions.

1) Situation: Complete hatch occurs over a 4-7 day period, and foliage development is normal.

   Action: Use one insecticide application when at least 50 percent of the larvae have matured to second instar and the remainder are still first instar. Foliage on white oaks should be 5-20 percent expanded and 30-50 percent expanded on other tree species. The Bt will not have lost any significant insecticidal activity by the time the remainder of the larval population matures to second instar and begin to feed.

2) Situation: Hatch is extended beyond 7 days but is less than 14 days, and foliage development is normal.

   Action: Use one application when 40-50 percent of the larvae are second instar. By then, about 5 percent will be third instar, and the remainder will be first instar with few still hatching. Foliage development on white oaks should be about 30-60 percent expanded and almost fully expanded on other species.

The Bt should be effective against the small proportion of third instar larvae and not lose any significant activity by the time the newly hatched larvae mature to second instar and begin to feed.

3) Situation: Hatch is extended beyond a 14-day period, and foliage development is normal.

Action: Use multiple applications at 5-7 day intervals. The first application should be made when about 30-40 percent of the larvae have matured to second instar. There should be no third instar larvae. Foliage on white oaks should be about 30-40 percent expanded and about 70 percent on other species. The last application should be made about 5 days after the last observed hatch. Such a situation is rare in the Northeast but not in the Northwest.

4) Situation: Hatch period is a normal 4-7 days, and foliage development is delayed.

Action: Use one application when at least 50 percent of the larvae have matured to second instar, but wait until foliage on other oak species is at least 60 percent expanded. Do not wait for foliage development on white oaks.

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3. SPRAY DEPOSIT ASSESSMENT

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Introduction

The monitoring, measuring, and analyzing of spray deposits are important factors in evaluating the success or failure of an aerial spraying project. For example, deposit assessment data can provide the basis for identifying swath widths and optimizing droplet distribution across the swath during aircraft characterization trials prior to the initiation of a project and for determining the proportion of insecticide that reaches the intended target or is lost to drift during a project.

The specific techniques selected for deposit assessment will vary depending upon individual objectives and desired accuracy. For example, is the objective to monitor and measure deposit that has reached the intended target, or that which has missed the intended target (e.g., lost to the ground or drifted from the spray area)? To compare the efficiency of aircraft configuration, or to relate deposits to biological effectiveness? In general, deposit assessment is a labor- and time-intensive effort requiring the use of large numbers of target collectors to overcome natural variability. Since pilot and operational projects are conducted on larger acreages than research projects, time and equipment constraints usually limit accuracy.

Spray deposit is characterized by four parameters: volume or mass of spray per unit area, numbers of droplets per unit area (droplet density), droplet size distribution, and area of drops per total area (percentage of area covered). Parkin and Wyatt (1982) review several techniques for measuring spray deposit, although they are generally divided into two broad categories, volumetric analysis and stain analysis. Only one of these parameters (volume of spray per unit area) can be measured using volumetric analysis; whereas, all four parameters can be measured and characterized using drop stain analysis techniques--image analysis and stain analysis.

Volumetric Analysis

This technique involves the measurement of the total volume or mass of deposit using washoff of the deposit on a target collector. Therefore, it is possible to assess the efficiency of an aircraft for specific meteorological conditions and to obtain information on the dose of active ingredient. There are several methods for estimating the volume or mass deposited:

- Colorimetry. Using a soluble colored dye (e.g., red powder 40) and colorimeter to measure the concentration of dye. Samples should be collected soon after spraying to minimize fading of the dye.

- Chemical analysis. Presence of actual active ingredient measured using gas chromatography (GC) or high-pressure liquid chromatography (HPLC).

- Fluorimetry. Using a fluorescent tracer (e.g., Rhodamine WT, soluble Brilliant Sulphaflavine FFA (BSF)). Analytical methods that use soluble fluorescent dyes are more sensitive than those that use soluble nonfluorescent dyes, although fluorescent dyes generally fade rapidly in intense sunlight. Different tracers vary in their stability in sunlight. For example, BSF is somewhat resistant to sunlight and can be left for a few hours in sunlight without much degradation. Check with the manufacturer on the stability of the tracer you intended for use.

The amount of dye/tracer in the washoff solution is compared with the amount originally added to the spray and, given the area of the target, the volume or mass of spray deposited can be calculated. The limitation of volumetric analysis is that the data only apply to the total mass (or original volume) of spray deposited. However, it is believed that a mass or volume measurement per unit of target area (e.g., for Bt, international units per cm^2 of target area) is the most biologically representative measure of the deposit.

Stain Analysis

This technique involves the measurement of droplet stains that provide data on droplet density, droplet sizes, percentage of area covered, and volume or mass of deposit (by sizing droplets and corresponding number counts). Several methods are available for estimating these parameters: visual assessment (e.g., using scale 1 to 10); manual counting and sizing, using a hand magnifier and graticule, and semi-automated sizing, using a small, microcomputer-based system of image analysis whereby a video image is digitized and automated measurements are made (Bryant and others 1987, and Last and others 1987).

One of the most important limitations concerning the use of droplet stains or impressions is the determination of spread factors that are used to convert stain sizes to droplet sizes (spread factor=stain diameter/droplet diameter). Typically, spread factors exceed one and vary as a function of drop diameter. It is desirable for accuracy to determine the spread factor for the specific tank mix and collection surface under conditions representative of field use. May (1950) developed the magnesium oxide (Mg0) method to determine drop sizes. This involves the production of a Mg0 thin layer on a glass slide by deposition from a burning magnesium ribbon. Droplets landing on the slide make a crater in the Mg0 layer, and the sizes of the droplets determine the sizes of the craters. The spherical drop diameter is the diameter of the crater formed by the drop penetrating the Mg0 layer multiplied by a conversion factor of 0.86. In determining spread factors, groups of uniform-size drops are produced by means of a vibrating reed apparatus or a serrated disk rotary sprayer, collected, and measured in the Mg0 layer and on the collection surface. Because the coefficient between drop size and crater size remains constant for different droplet sizes, the size of each droplet class and a spread factor conversion for the collecting surface can be determined.

Droplet Behavior

Before discussing the various types of targets and collecting surfaces available for capturing drops, a brief summary of droplet behavior is appropriate. As discussed in Chapter I, a drop falling in still air will accelerate until its aerodynamic drag is equal to gravitational force; thereafter, it will continue to fall at a uniform velocity. This terminal velocity depends on the density and size of the drop. As the flow of air approaches a target surface, it is deflected around the surface. The ratio of the number of drops that impact on the collecting surface of the target to the total number of drops approaching the surface is called the "collection efficiency" of the target. The collection efficiency is affected by 1) size, shape, type of collecting surface, and position of the target; 2) density, diameter, and velocity of the drop; and 3) velocity and direction of the air flow (Barry and others 1978). In general, collection efficiency can be increased by: 1) Increase in airspeed of the drop around the target, 2) decrease in size of the target, 3) increase in drop density, and 4) increase in drop diameter. The collection efficiency for a given target will differ for each size drop and for wind speed; therefore you should measure wind speed at the target site.

Target Size and Orientation

The selection of targets for collecting spray droplets will depend on the spray deposit parameters being measured and the droplet sizes.

Target size is important, since large-sized targets collect more spray for measurement and are effective at collecting medium or large drops due to their larger area, but give inaccurate assessment of sprays containing small droplets. A small-sized target is an effective collector of both large and small drops and should be used wherever practical or where accurate assessment of fine spray is required. However, because such targets need to be small to efficiently catch small droplets, they cannot collect much deposit. Since droplet size, wind speed, and their interaction affect mean descent angle of the droplet, the orientation (e.g., horizontal, vertical) of the target should be chosen to best intercept these falling drops. For example, vertically oriented targets should be used for small and horizontally drifting droplets, whereas, horizontally oriented targets should be used for larger, low-wind, and vertically falling droplets.

Collecting Surface

The collecting surface of the target will affect the selection of techniques available for measuring spray deposit, subsequently, the accuracy of those measurements. Also, droplets are more likely to bounce from a smooth surface than from a rough one. Target shape is also important. Flat targets are suitable for collecting medium or large drops in low winds, thin cylindrical targets may be used for medium to fine drops, and biological targets like leaves best represent what will actually be caught in the field. In general, targets with concave forward surfaces tend to have better catching characteristics. Targets with threadlike appendages are likely to capture a lot of small drops. Artificial targets can be modified into the shape of the natural target (e.g., cutting Kromekote cards into the shape of a 75 percent expanded red oak leaf (see Reardon 1987).

During aircraft characterization, flat targets are positioned on or near the ground to collect a range of drop sizes biased toward large droplets because of their (flat targets) low catch-efficiency. For determining canopy deposit, natural targets (e.g., leaves, needles) that are positioned at various strata in the canopy with associated moderate catch-efficiency are suitable. For determining drift, however, a target with high catch-efficiency for small droplets is needed because airborne particles are usually being measured.

Types of Targets

Targets are usually put in two general categories: air samplers and stationary impact surfaces (Last 1987). There are many types of targets in each category, although only the ones more commonly used are discussed here.

Mechanical air samplers. These are used to sample droplets less than 100 µm for measuring drift or for complete spray accounting. The objective of the mechanical sampler is to increase the collection efficiency either by moving the collector at high velocities relative to the droplet or by drawing in an air sample from which droplets can be removed or filtered. Mechanical air samplers include rotary collectors that rotate the target (e.g., rotating rods or wires) and suction collectors. A suction collector draws in a volume of air and, by directing it against some obstacle, provides an efficient collection of drops. It should be operated such that the air streamlines upstream of the collector are not affected by the collector. Examples of suction collectors are collection filters (e.g., Staplex Air Sampler) and impactors (e.g., cascade-type). A cascade impactor has several impaction stages; at each stage, an air nozzle causes the drop to impact onto a glass slide. The width of the nozzles reduces progressively at each stage, resulting in an increase in air speed and the reduction in mean drop size collected at each stage. Rotary collectors have two major disadvantages: 1) Excessive power requirements and 2) difficulty in manipulating the deposit collected on the surfaces for analysis by microscopy. There are two disadvantages usually associated with suction collectors: 1) A sample of air can show droplet size bias of the collector if affecting the air upstream of the collector, and 2) suction collectors require an external power source for pumping. In general, air samplers are expensive and require an intensive effort to analyze the recovered deposit.

Stationary impact surfaces. These are used more frequently than air samplers because of their simplicity. Ideally, the target shape and size are selected so that they match that of the natural target as much as possible. The surfaces of the target (or the target composition itself) are chosen to allow measurement of the droplets after impaction. Common collecting surfaces are: sensitive paper, glossy paper, filter paper, acetate, liquid media, and natural surfaces.

Sensitive paper. Dye-coated sensitive papers (76 x 26mm) are commercially available for both water and oil formulations (Spraying Systems 1983). The water sensitive papers are yellow in color (i.e., yellow layer of bromoethyl blue), which turns dark blue when in contact with water or aqueous solutions. Several limitations are associated with water-sensitive papers: very humid conditions (greater than 80

percent relative humidity) can cause the paper to turn blue; droplets less than 50 µm will not stain the paper if the humidity is less than 40 or 50 percent, since they evaporate before staining; and spread factors vary strongly with varying relative humidities, as does the sharpness of the stain. The oil-sensitive paper is a black-colored paper coated with a thin, white-colored, oil-soluble wax surface. The waxy surface is dissolved by oil-based droplets, leaving black marks. Several limitations are associated with oil-sensitive papers: droplets less than 30 µm may not stain the paper, not all oils will mark oil-sensitive paper, and spread factors vary with formulation and droplet diameter. Several advantages exist with the use of sensitive papers. They permit the monitoring of spray deposit without the need to add a dye or similar material to the spray formulation and are available commercially. However, as stated above, they should not be used to determine droplet sizes because the spread factors vary, although they can be used to estimate droplet density (e.g., drops/cm²) and area coverage. The main disadvantage in using only droplet density data arises when the biological activity is closely related to the volume deposited. Increases in droplet numbers per unit area can sometimes produce a decrease in the actual spray volume (i.e., small droplets contribute little to the volume of spray deposited but produce large numbers of droplets per unit area--cubic relationship between droplet diameter and volume).

<u>Glossy paper</u>. Kromekote® paper (a cast-coated highly calendered stock) has been used for many years. It is usually white in color and is commercially available from several sources (e.g., Paper Plus, 92 Weston Street, Hartford, Connecticut, (203)724-9671. Ask for Mead Mark 1, 10 int cover stock). It is advisable to use papers that are glossy on both sides to prevent moisture from penetrating and bending the nonglossy side. The glossy side of the paper should be exposed to the spray. A dye is added to the tank mix for visibility (i.e., a more permanent record of and more defined spray deposit). Kromekote papers can be dyed black for selected insecticides (e.g., Diflubenzuron). Kromekote papers can be used to provide an estimate of droplet size and density, and area of coverage, although the sizing of droplets is complicated by difficulty in accurately determining spread factors. For oil-based formulations, Maksymiuk (1964) developed the D-max method (i.e., the DV.5 of a spray is estimated by the measurement of just a small percentage of the total spectrum), which provides a general estimate of drop size. Since spread factors are not readily available for most tank mixes, 2 is used for water-based and 8 for oil-based formulations. Kromekote papers can be placed horizontally or vertically, wrapped around cylindrical collectors, or cut into narrow strips. The collectors utilizing Kromekote paper can be located at various vertical strata from the ground to the top of the tree crown, although for practical reasons, they are usually located at or within 2 meters of ground level.

<u>Filters</u>. Gridded cellulose triacetate membrane filters (e.g., Millipore Filter Corp.-Bedford, Massachusetts) can be positioned within the intended spray area and are useful especially for *Bacillus thuringiensis* (Bt) sprays to determine whether or not the area received treatment and the approximate number of droplets/cm² (e.g., Bt colonies/cm²). After exposure, the filters are placed on Tryptic soy agar, incubated at 25°C for 6-10 hours, and the number of Bt colonies counted under a dissecting scope.

<u>Acetate</u>. Acetate has been used as a collecting surface for volumetric spray recovery (Bryant and others 1987). Thin sheets (0.005") can be washed in aqueous solvent to dissolve spray for fluorometric or colorimetric analysis. Background contamination should be determined by placing some acetates in the field before spraying. These background acetates are picked up before the spray application. Remember that fluorimetry has a higher level of sensitivity and accuracy than colorimetry (theoretically, 0.01 parts per billion and 0.1 parts per million, respectively), although the equipment for the former is more expensive.

<u>Liquid media</u>. The use of a liquid media in containers, e.g., 2.5 percent peptonized water in autoclavable polymethylpentene containers, to collect deposit is

useful for microbial sprays, especially for Bt, to assess the number of viable Bt spores deposited. The containers are placed open prior to and for 30 minutes after Bt treatment, closed, placed under refrigeration, and the liquid media passed through a series of dilutions and placed on nutrient agar (Smirnoff 1981). This technique is time-consuming and labor-intensive, although it has been used extensively by Canadian researchers to monitor Bt deposit during spruce budworm operational programs.

Natural surfaces. The use of natural surfaces such as leaves or needles on the target plant species for monitoring deposit will provide the most accurate representative of deposit to be encountered by the pest species; therefore, this method is especially useful in attempting to relate deposit to mortality. Unfortunately, leaf surfaces are non-uniform, perishable, and require the use of a dye tracer, usually fluorescent, that allows the droplet to be seen as a coherent stain (Uk 1977). If fluorescent tracers are added to the tank mix, an ultraviolet light can be used to detect deposit. Foliage area can be calculated using an area meter (e.g., Licor 3000 leaf area meter). Based on previous studies, only deposit on the upper or exposed leaf surface needs to be measured, since the deposit on the lower surface is minimal. If leaves are a problem, the leaves can be photographed and the deposit measured by image analytical techniques from the photographs at a later date (Bryant et al. 1987, Last and Parkin 1987).

Procedures for Deposit Assessment from Stationary Impact Surfaces

Sensitive paper. A hand lens or microscope should be used to count drop density. Place a template with pre-identified areas (e.g., 1 cm^2) at each of four locations on the paper. Place the magnifier over the template, count the number of droplets within each area (if the total number of droplets is less than 100, then count additional areas), calculate the average number of droplets/cm^2 for each collector, and then, calculate the average droplet density and coefficient of variation (see Chapter II) for all the papers in a given area. Suggestions for field use: 1) Gloves should be used for handling the papers to avoid staining and contaminating; 2) the support for the papers must be dry; 3) paper surfaces should not be scratched before use; 4) papers should be stored under dry conditions, and 5) papers should not be retrieved while the deposit is still wet (Spraying Systems 1983). In small plots or large areas near environmentally sensitive or difficult-to-spray areas, the papers can be placed along a transect bisecting the area. The actual numbers of papers used and their location (e.g., stapled onto leaves in tree crowns) will depend on support personnel, available time, and monitoring objective.

Kromekote paper. The same techniques used to determine droplet density on sensitive papers can be used for Kromekote papers. The determination of drop sizes can only be done if a spread factor is used to convert stain sizes to drop sizes. For a general estimate of VMD, the D-max method can be used with a hand magnifier and graticule. The procedure for determining the VMD using the D-max method is as described in Maksymiuk (1964): 1) Allow at least 10 minutes for the droplets to spread and dry on the cards before measuring the spots; allow more time for very large droplets or for spray formulations that evaporate slowly. 2) After the spots stop spreading, select and measure the diameters of the five largest spots. Measure the spots to the nearest 100 µm (0.1 mm). Tabulate the spot diameters in order of decreasing size, as shown in the example under step 4 below. 3) Convert the spot diameters to spherical droplet diameters by dividing the spot diameters by the proper spread factors. 4) Select the D-max droplet. The D-max is the largest droplet diameter in the continuous droplet spectrum with not more than a 32-µm difference between it and the next largest droplet--going from the smallest droplet size up. In the following example, droplet D-max is 390 µm:

Spherical droplet diameter	VMD, for aircraft Slow speed	Medium speed	
	---Micrometers---		
637	–	–	*(Oversize droplets*
606	–	–	*ignore)*
390	177	156	
375	--	–	
375	–	–	

Droplets larger than D-max are only found occasionally. They are sometimes caused by leaks or by spray dripping from the equipment or from the aircraft surfaces. If they are present, check your spray equipment.

Converting droplet D-max to VMD. The conversion factors for converting droplet D-max to VMD for different speed aircraft (2.2 and 2.5) were developed by Maksymiuk (1964), and the precision of the method is given by Moore and others (1964). 1) Obtain VMD as follows: a) Slow-speed aircraft--divide spherical droplet D-max by 2.2, or simply multiply it by reciprocal 0.454, b) medium-speed aircraft--divide spherical droplet D-max by 2.5, or simply multiply it by reciprocal 0.400. 2) Because VMD varies from flight to flight (Moore and others 1964), use the average of not less than three test flights.

For a more precise estimate of droplet deposit, an image analyzer and an automatic data processing program to analyze the spot count data and compute spray deposit parameters should be used to process the papers and spread factors determined for specific field conditions. Image analyzers (e.g., Optomax, ITI, Burlington, Massachusetts) are available at the Pesticide Research Laboratory, Pennsylvania State University, University Park, Pennsylvania (contact Dr. William Yendol, 814-863-4432), or at the Northeast Forest Experiment Station in Hamden, Connecticut (contact Normand Dubois, 203-773-2026). Since these image analyzers are expensive to purchase (approximately $30,000), a less expensive and equally accurate portable system "Swath Kit" is available through Bio-Aeronautical Technologies, State College, Pennsylvania (contact Wade Sheen, 814-865-3882). If an image analyzer is used to measure and characterize deposit, at least 200 drops per card should be read. Drop size is usually expressed in volume median diameter (VMD or DV.5). The actual placement and numbers of cards located in the field will depend on those factors discussed earlier for sensitive papers. Kromekote cards should be kept dry while in storage, labelled on the nonsprayed surface of the card, supported using a device not extending beyond the border of the card, placed in the field as near to spray application as possible, left out for at least 15 minutes to dry after the spray is applied, handled on the card edges, and stored in a slotted container for transportation. Maximum drying time and the use of slotted containers for transportation are especially important considerations when an oil-based formulation is used. In general, Kromekote cards used as horizontal collectors are not a satisfactory way of collecting very small droplets (less than 80 μm) in conditions other than that of negligible wind speed. However, their ease of use, combined with their capability of catching the larger droplets, make them popular in use for aircraft characterization.

Gridded filter. Black gridded membrane filters can be used to determine the approximate number of Bt colonies/cm^2. Following placement on Tryptic soy agar and proper incubation, a dissecting scope is used to count all colonies in five sets of four squares (each set of four squares = 0.36 cm^2), multiply by 9.64 (= total count on filter) and divide by 17.35 (= colony count/cm^2). This collecting surface is fairly expensive, and growth of various microrganisms (other than Bt) on the filters complicates the

analysis. The actual location and numbers of filters placed in the field will depend (as for Kromekote cards and sensitive papers) on available field personnel, resources, and desired objectives.

For pilot and operational projects, oil- and water-sensitive cards provide an inexpensive and commercially available target for collecting data concerning whether an area received spray deposit or was missed and an estimate of drop density reaching that area: Gridded filters are relatively expensive but provide an additional method for obtaining an estimate of drop density and for Bt tank mixes, an estimate of Bt colony density. Kromekote cards (dye added to tank mix) provide a very inexpensive method to determine whether an area received deposit and an estimate of droplet density, percent area covered, drop sizes, and mass or volume deposited. Remember that vertical cylinders are better targets than horizontal ones under all conditions except where there are large drops in low wind speeds. Due to difficulties in determining spread factors (i.e., the ratio of the diameter of the stain to the diameter of the drop causing it) and expense of image analyzers, the D-max method is often used to estimate VMD using spread factors of 2 or 8 for water- and oil-based formulations, respectively. Nevertheless, due to the inaccuracies of determining spread factors, the mass or volume deposited should be considered an estimate. Acetates can be used for volumetric spray recovery and provide data on volume or mass per unit area. They are usually used along with Kromekote cards, although deposit washoff and processing are time-consuming. Since we cannot relate deposit collected on Kromekote cards positioned on the ground beneath the target to deposit on foliage in the canopy, it is always preferable to measure deposit directly from the natural surfaces (e.g., leaves) especially for relating deposit to mortality.

In order to obtain an image of a drop on foliage, it is necessary to use a fluorescent tracer that retains a high degree of fluorescence when the drop dries. The fluorescent tracers rhodamine or BSF are added to the tank mix at the rate of 10 gm dye per gallon of spray. Additionally, deposit can be washed off the foliage and analyzed fluorometrically to determine the mass of dye, and by assuming a fixed ratio between dye and active ingredient, the mass of active ingredient present. Unfortunately, the inaccessibility of foliage from various vertical strata and the associated difficulties in processing and analyzing the deposit preclude this technique for use during operational programs where large acreages need to be monitored and large numbers of samples need to be collected due to high variability.

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4. AIRCRAFT CHARACTERIZATION USING AUTOMATED WEATHER AND DEPOSIT ANALYSIS

Jon Bryant
and
Richard Reardon

AIRCRAFT CHARACTERIZATION USING AUTOMATED WEATHER AND DEPOSIT ANALYSIS

Introduction

One of the most difficult tasks in applying insecticides for agriculture or forestry is assessing the performance of the aircraft used to apply the insecticides. Not only are measurements difficult to make, but the time and effort required to get the results has often meant aircraft characterization has been overlooked or, at best, not been practical on-site. Solving this problem requires a tool that can make weather and deposit measurements on-site and display results within a short time after the spray run was made. It should also be able to present the results simply to pin-point problem patterns; thereby, making adjustments to the spray system configuration. An incidental advantage to such a tool would be it's teaching influence, allowing users to associate causes and effects, enabling first-hand learning about the factors which affect deposit patterns.

The Swath Kit was designed for the USDA Forest Service Northeast Area State and Private Forestry to fulfill the objectives described above, providing a tool which can be used prior to the application of insecticides to forested lands in the east each spring for the control of hardwood defoliators. It's utility, however, extends beyond this narrow scope into agricultural and public health applications.

The Swath Kit is used as one part of a sequence of operations in preparing an aircraft for spraying. Prior to the use of an aircraft in aerial spraying operations, two vital tasks must be accomplished. First, the atomizer type and size, based on the volume of spray to be applied per acre, and the aircraft and the droplet size spectrum to be used, must be selected. The aircraft needs to be calibrated to ensure that the correct output is achieved, given the application speed of the aircraft and the distance between successive passes of the aircraft flights (lane separation). This does not present a technical problem since only manufacturer's technical data sheets and a hand calculator are required. However, the aircraft should not be flown until the shape of the deposit pattern beneath the aircraft has been inspected. This second task is a much more difficult problem if more than a visual inspection of the deposit shape is to be made. It is at this stage that the Swath Kit is employed.

The Swath Kit can be divided into three parts according to the three broad tasks which comprise this next characterization phase of the aircraft set-up.

1) Weather and Application Detail Recording: Much data are lost from the pool of available knowledge about spray performance because insufficient supplemental information is recorded about the conditions of the spray application. Recording of the settings and conditions of the spray application are, therefore, vital to explain the results. The weather must also be monitored during a spray application to ensure suitable conditions exist for the characterization test. The parameters wind speed, wind direction, temperature and relative humidity are the minimum measurements required to describe the weather. These data should be presented visually to help the user make quick go/no-go judgements on the suitability of the weather. When a spray run is made, data should be recorded for later comparison with deposition.

2) Deposit measurement: Having sprayed over a card line, the deposit on the cards must be measured. Deposit can be presented in a number of different ways: volume of spray per unit area, number of droplets per unit area or percentage of the surface area covered with spray. Also of interest are the sizes of the droplets. An image analyzer, a tool which can look at a card and make measurements based on that image, can provide all these measurements.

3) Pattern assessment: When all the cards have been measured the pattern of the deposit beneath the aircraft must be assessed. Problems in the pattern, such as the presence of peaks or valleys, and assessing the effective width of the pattern, can be made at this stage in conjunction with the weather and trial recordings.

To accomplish these tasks a combination of hardware and computer software has been constructed. The system revolves around a portable computer which acts as a multipurpose data recorder and analyzer. Weather information is fed to the computer from an anemometer, a wind direction vane, a temperature thermocouple and humidity probe. Image analysis is performed by a high resolution camera and image-grabber board. Data is stored on a hard disk for later analysis.

All the software programs have been designed for ease of use in the field; wherever possible, settings are remembered between days, values are not entered by hand where they can be done automatically and complex inputs are made easy by selection of items from menus. A context sensitive help system, which provides help screens pertinent to the current position of the cursor, aids in choosing selections or inputting data.

Data presentation is made easy by using graphical displays and all data can be printed for permanent record.

The only requirements for the system are that a visible dye be added to the spray solution and targets are clean white cards. Typically 3 lb per 100 gallons of spray mixture of a powdered food dye such as FD & C Blue #1 or Red #40 (Chemcentral, 13395 Huron River Drive, Romulus, Detroit, MI), or 0.4 gallons per 100 gallons of spray liquid of Rhodamine WT (Keystone Analine Corporation, 2501 West Fulton Street, Chicago, IL), will be sufficient to dye water. These conditions must be met to allow the image analyzer to measure deposit.

Operating the Swath Kit

The following description takes you through a typical spray run showing you some of the data screens that would be entered on the computer and some of the outputs.

Starting conditions. The aircraft arrives at the airfield. It may be a different aircraft, a different nozzle type or configuration, or simply a different spray formulation that you want to monitor. You begin by calibrating the aircraft to establish the correct flow rate and then begin the Swath Kit to determine the spray deposit pattern.

Stage 1 weather. At this stage in the characterization trial it is advisable to enter as many of the application parameters as possible. For example, where was the trial done, using what aircraft and spray system, applying what insecticide and dilution? These data, and the weather results taken actually during a spray application, are stored in a special file - the Information File. Data entry is made easy by a special data input screen (Fig. IV-4a). The data input screen is comprised of fields into which data must be typed. Each field has a special one-line instruction which automatically appears on the bottom of the screen to help identify the type of information needed and, if necessary, the acceptable numerical range for that data. More comprehensive help can be accessed from the on-line help system by pressing the F1 key.

When the trial information has been entered you can move on to the weather recording screen.

The information stored in an Information File can be retrieved and further edited at some later time from other parts of the Swath Kit program - deposit measurement and pattern assessment.

The weather recording screen (Fig. IV-4b) shows the current readings for wind speed, wind direction, temperature and humidity, updated every 2 seconds. The means are also shown for data recorded over the last 10 minute period. The trend for a chosen weather parameter is also shown graphically. This allows rapid judgement on, for example, changes in wind direction. The direction of the wind relative to the card line orientation is important. If applications are made when the strength and direction

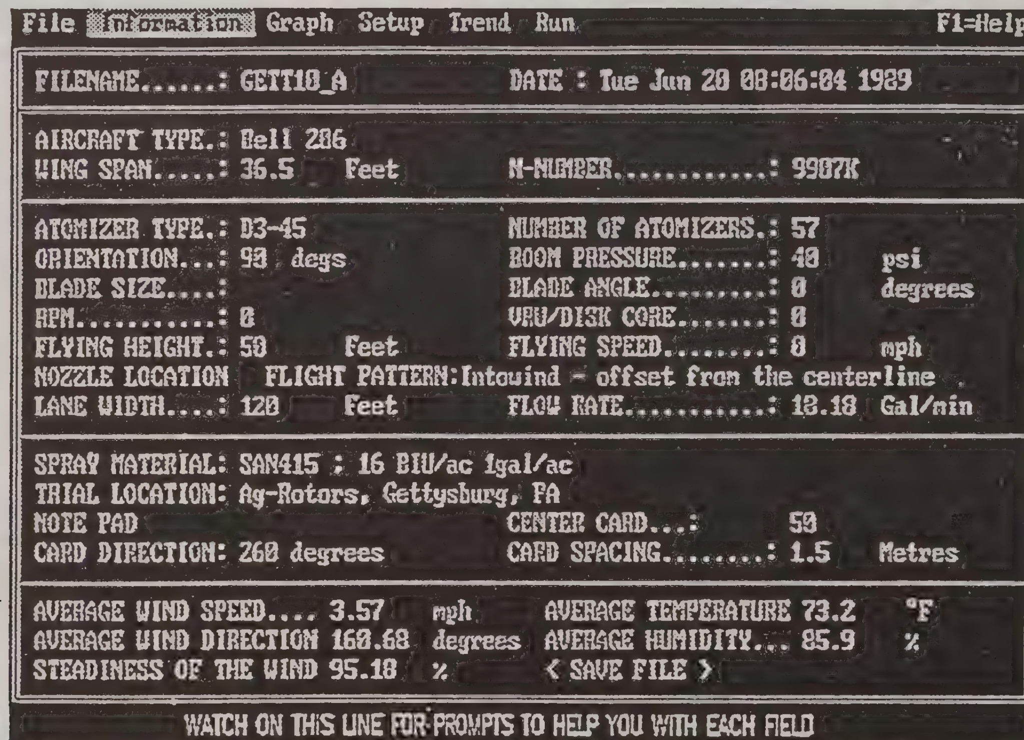

Figure IV-4a. Information File screen used to input application parameters about a characterization trial.

of the wind are misjudged then the resulting displacement of the swath may mean much of the pattern misses the card line. To help judge wind direction relative to the card line a graphic display shows the card line as a dashed line and a moving solid line shows the current wind direction.

Weather recordings are made automatically. When the aircraft passes over the card line you push the Enter key. This starts weather recording for the next 5 minutes. This is joined with 5 minutes of data taken just prior to the spray application to form 10 minute summaries which describe the weather at the time of spray. These data are:

a) Average resultant direction. This describes the overall wind direction over the ten minutes of the spray trial. It differs from a simple arithmetic mean of the directions because it is formed from a combination of wind direction and wind speed information. Thus, a wind direction of 180 degrees at 10 mph is given more influence than a similar direction but at 2 mph. This is a more representative statistic because it describes the overall direction that a droplet cloud would drift after ten minutes, something an arithmetic mean does not do.

b) Resultant speed. This is formed by dividing the distance that a droplet would travel, from it's point of release, by 10 minutes, the total recording period. Again this figure differs from a simple arithmetic averaging of the wind speeds but is more representative of the influence exerted on a spray cloud.

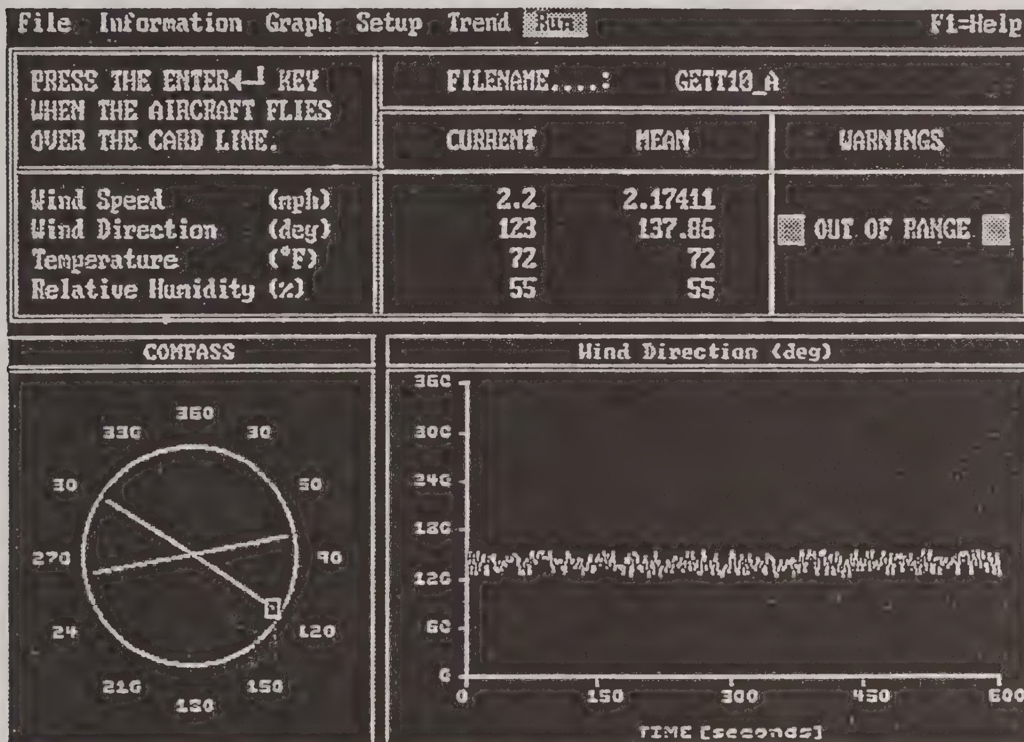

Figure IV-4b. Weather recording screen showing the current weather conditions, average weather conditions over a ten minutes and the graphical presentation for wind direction over the same ten minute time frame.

c) Steadiness. The wind direction and speed change over time. The steadiness figure describes by how much. A value of 100% means that the wind direction did not change over the 10 minute period. As wind direction and speed begin to fluctuate the steadiness value reduces toward 0%.

d) Average temperature. A simple average of the temperature over the 10 minute recording period.

e) Average humidity. A simple average of the relative humidity over the 10 minute recording period.

In addition to the summary statistics described above the Swath Kit stores the raw data for each sensor (300 values for each) with the information file. This means that at some time in the future, when you are trying to explain the shape of the spray pattern, you can replay the weather information for the spray period in the form of graphs and see what the spray cloud was subjected to (Fig. IV-4c).

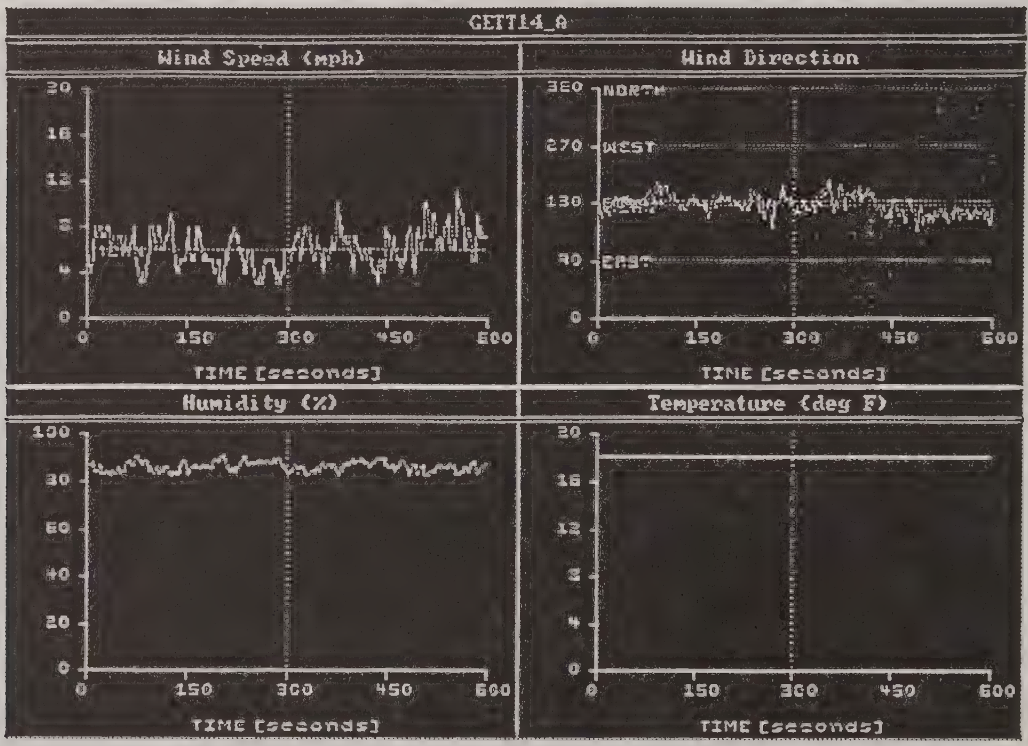

Figure IV-4c. Summary weather displays showing a ten minute time frame for wind speed, wind direction, temperature and humidity. The central vertical line shown the time the aircraft actually passed over the card line.

Image Analysis

After you have made a spray run, the deposit on the cards must be measured and a spray deposit profile constructed.

First, the deposit measurement software must be told what spray material is being used by selecting the material from a menu of spray formulations. This provides the computer with information about the way the spray spreads when it hits the card and conversion units display the mass per unit area deposit measurement in common units such as IU/cm^2 or grams active ingredient per square inch.

Once the set up is complete the card measuring can begin. Starting with the first card in the card line, and progressing in sequence across the whole card line, the computer will prompt you to hold a card in front of the camera to make a measurement, then display the results (Fig. IV-4d). For each card the measurements should be completed in as little as 30 seconds. This means that a full deposit pattern should be able to be analyzed in roughly the time it takes to reestablish the next card line and next aircraft configuration. In addition to the single card results the screen also shows a simple graphical presentation of the whole pattern as more and more cards are measured.

A full plot of all deposit parameters is possible once you return to the initial menu screen (Fig. IV-4e).

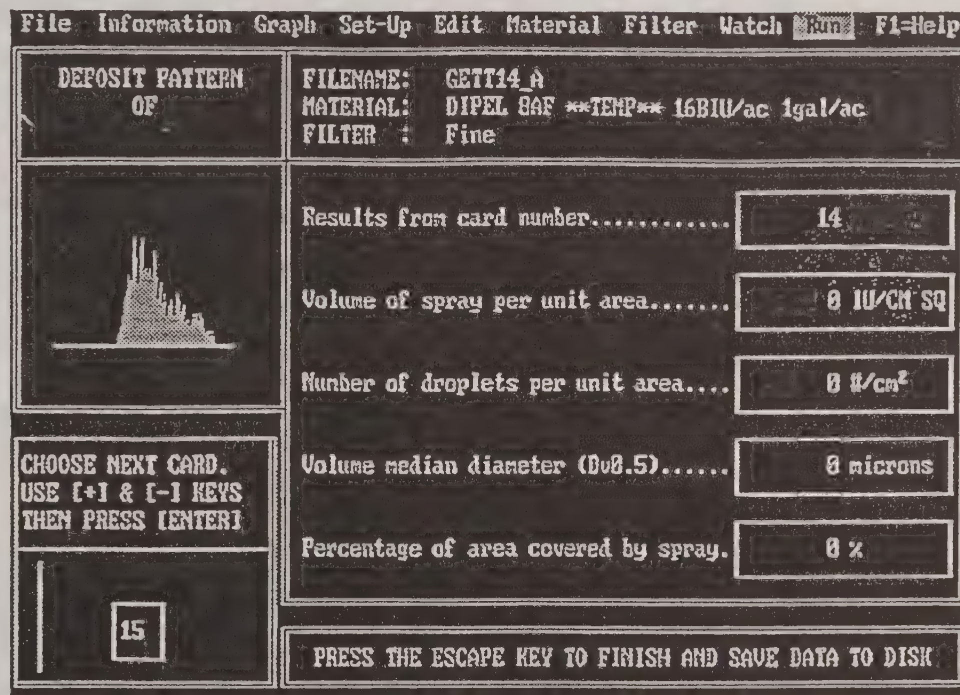

Figure IV-4d. Card reading using the image analyzer. The figures on the right of the screen display are the deposit summaries for the last card read. The graph on the left of the screen is the deposit pattern beneath the aircraft measured so far.

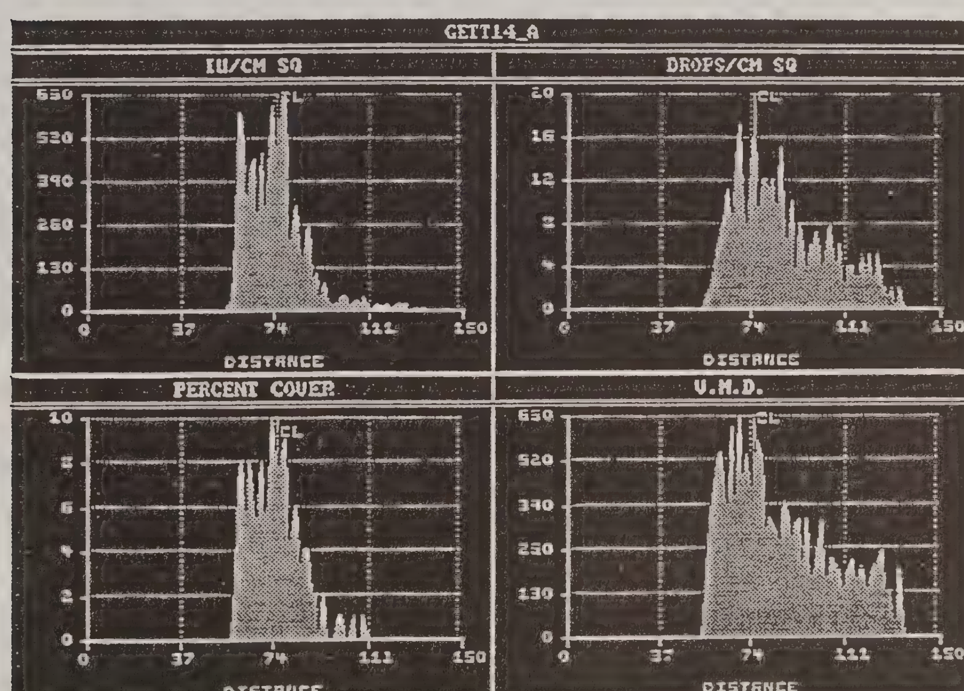

Figure IV-4e. A complete plot of all deposit parameters obtainable from the initial menu screen.

Pattern Assessment

We now have enough information to start the pattern assessment process.

The following is a list of tasks which can be undertaken.

a) Examine the spray deposit pattern. The first job might be to establish if the shape of the deposit beneath the aircraft conforms to the ideal even shape e.g. a broad flat rectangle with gently sloping edges. The Swath Kit displays a single pattern using any of the deposit measurement parameters described above (Fig. IV-4f). Peaks and valleys can be easily seen. If problems exist you may want to re-configure the aircraft and re-run the characterization trial. It may require repeated characterization runs before you move from this stage.

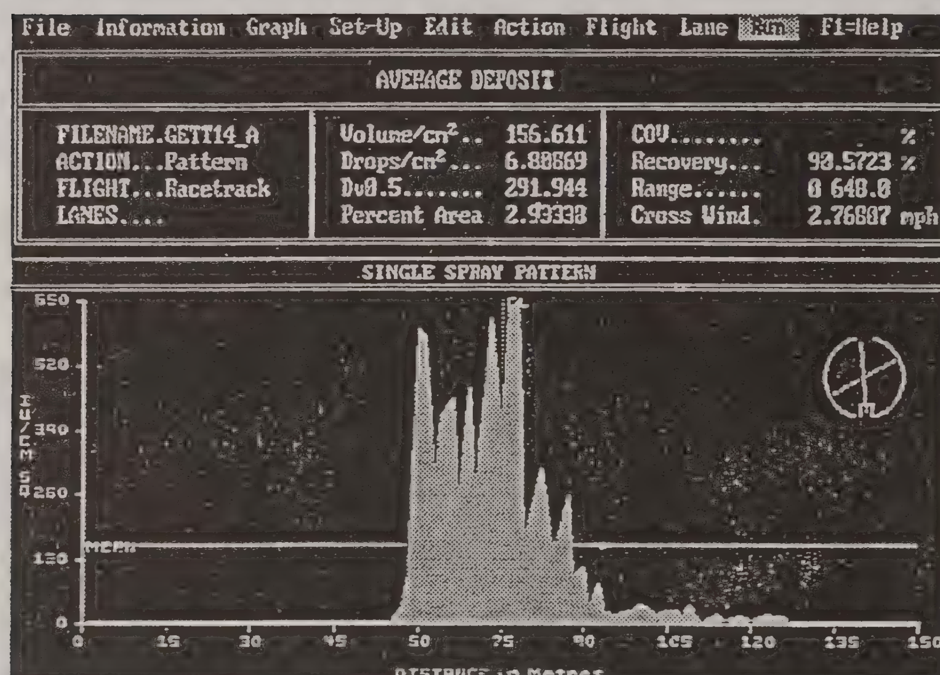

Figure IV-4f. A single spray run of the aircraft produces a spray deposit pattern on the ground. This pattern is displayed along with summary statistics about the mean, peak values and wind conditions at application.

b) Examine the width of the spray pattern. Although the Swath Kit will rarely be used for operationally establishing the ideal lane separation of an aircraft, it is useful to compare the setting chosen during calibration with the overall widths achieved during the characterization trial. Large short-falls in pattern width will be obvious, making recalibration and recharacterization necessary. However, this is a small cost compared to the waste and cost of underdosing and poor control which can occur if incorrect lane separations are used.

c) Overlap simulation. Having a single deposit pattern which you feel represents the typical output from that aircraft is useful, as described above. However, the Swath Kit allows you to simulate a field application to study the type of overlap deposit you might expect. This has the usual caveats associated with any simulation, but it is a useful tool to investigate the effects of lane separation changes on the resulting mean field deposit and the coefficient of variation of that deposit. The Swath Kit will graphically display the deposit profile from the overlap (Fig. IV-4g).

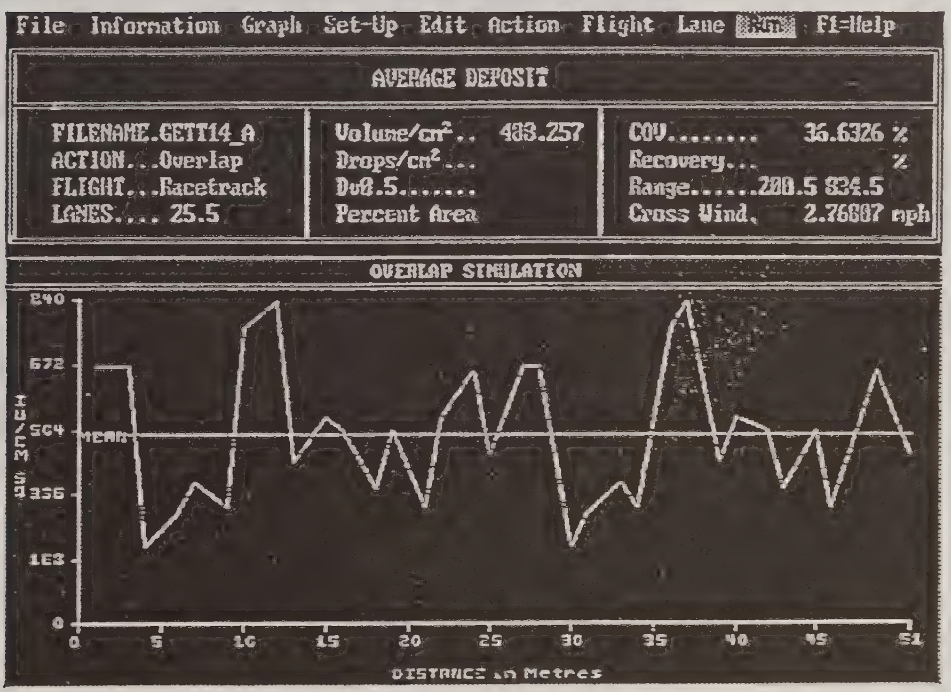

Figure IV-4g. Overlap analysis using multiple simulated spray runs to construct a predicted field deposit pattern. Summary statistics show the mean deposit achieved and the coefficient of variation for the deposit. Recovery figures determine what percentage of the spray emitted from the aircraft was actually measured on the cards.

d) Lane separation analysis. There is a rapid way to investigate the effect of changes in lane separation on mean field deposit and the coefficient of variation. You can get the Swath Kit to run multiple simulations between a range of lane separations. This results in a display of the mean deposit and variation for all the lane separations between the upper and lower limits you chose (Fig. IV-4h). From this you can quickly see the effects of badly judged spray runs, where lanes were flown too wide or too narrow.

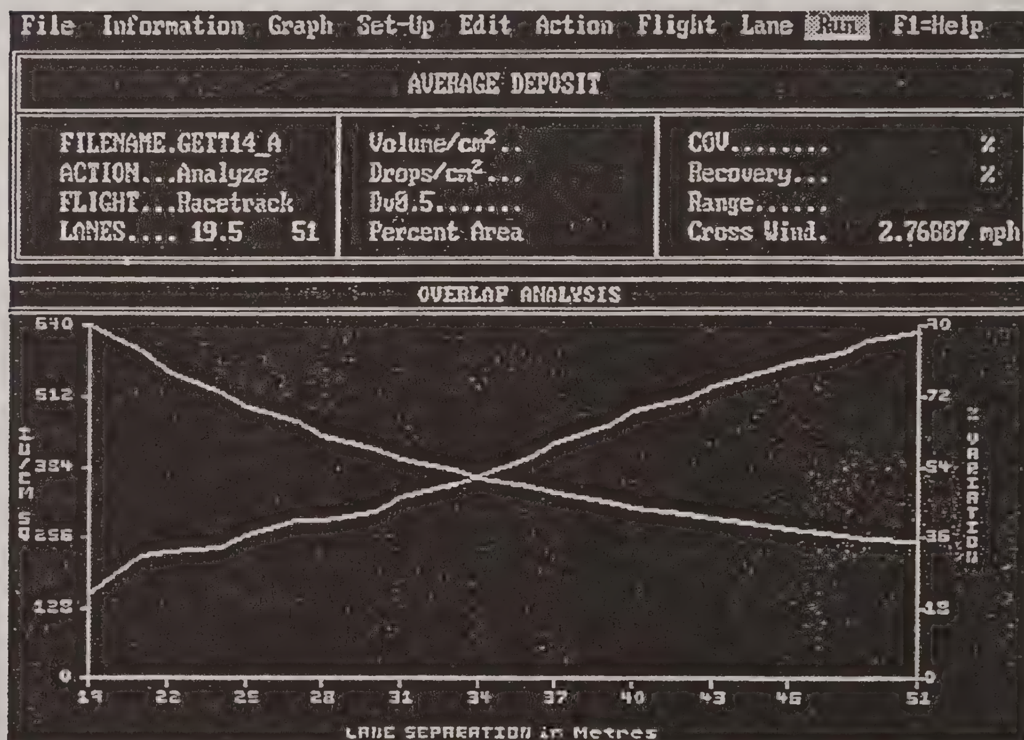

Figure IV-4h. Lane separation analysis where multiple simulated field applications are made over a range of lane separations. The graph shows the change in mean deposit (left axis, downward sloping line) and the rise in deposit variation (right axis and upward sloping line) associated with increasing lane separation.

Summary

The Swath Kit is a powerful tool for use in the field to aid in aircraft characterization. It's design is based on a portable computer which centralizes much of the data processing and analysis, making operation simple and the construction compact. The use of simple, specially designed software, and a comprehensive 12,000 word on-line help system, make learning to use the Swath Kit quick, and getting results easy.

Reference

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5. AIRCRAFT GUIDANCE and FLIGHT PATH RECORDING

Dennis Souto
and
Billy F. Tanner

Aircraft Guidance

Dennis Souto

Introduction

The success of an aerial spray project is dependent upon many factors. Pre-spray consideration should be given to clearly show where certain actions are to take place (e.g., turning spray booms on or off, or beginning a new flight line). Spray pilots need to know clearly defined spray block locations, what the boundaries are, and where the flight lines are located. Ideally, the pilot should be able to pinpoint an exact location on a map or aerial photo at any given time. Proper guidance can help minimize errors such as: 1) Spraying of non-designated target areas; 2) failure to spray areas scheduled, and 3) target areas receiving too much spray. Two major sources of mis-spraying are related to block design and pilot/guide error.

Block Design

Spray blocks should be designed based on biological need and ease of treatment. For example, gypsy moth-infested stands are initially proposed for treatment based on population densities, tree values, prior defoliation, etc. Once these areas are designated, they must be organized into spray blocks that consist of parallel flight lines (Oliveri 1979). Long flight lines are preferred because turning time is minimized, and productivity increases. Long flight lines do not necessarily mean that only large blocks can be treated. In fact, gypsy moth spraying frequently occurs in long, rectangular blocks to protect forested residences along roadways.

Each flight line needs an easily recognized feature to mark where spraying begins and ends. Prominent man-made or natural features make excellent endpoints for flight lines. Examples of man-made features include roads, power lines, housing developments, cemeteries, racetracks, water towers, schools, churches, gravel pits, railroad tracks, and agricultural lands. Examples of natural features include bodies of water (streams, rivers, ponds, lakes, reservoirs), topographic features (ridges, mountains, valleys, bogs, and swamps) and cover type changes (hardwood/softwood, natural forest/plantation). In gypsy moth spray projects, ridges and roads are frequently used to design spray blocks.

Features not readily seen from the air, like township lines or ownership boundaries, should be avoided. If such features must be used, then, marking devices are needed (Maksymiuk 1975). Markers may be balloons or paper/plastic materials placed high in the tree's crown or above it to define corners or boundary lines. Helium-filled weather balloons of highly contrasting colors can be seen by pilots and are the most commonly used marker. Limitations are: 1) Balloons quickly lose their helium and must be placed just before treatment; 2) helium tanks are awkward to carry to remote points; 3) wind can move the balloons away from designated points. Flares and smoke are other kinds of markers that share the same limitations as balloons. Fluorescent streamers or panels have a major advantage because they can be deployed several days before spraying. Panels and streamers can be placed by tree climbers or shot into tree crowns with slingshots or crossbows or dropped by aircraft.

The numbers of markers used should be minimized because too many can distract or disorient pilots. Another reason is so that spray aircraft are not waiting (losing valuable spray weather) for ground crews to finish setting up the next spray block. Make sure the pilots know each marker's location and significance.

Maps or Photos

The basic tools for any guidance system are a topographic map or aerial photo that displays spray blocks and the surrounding area. The most important aspect of any map or photo is that surface features visible from the air appear on the map or photo. Many types of maps or photos exist, and for any project, the choice will depend on several factors. First, the relationship between map scale and block size is important. The

map should be as large a scale as possible to show maximum detail, but small enough to contain the entire spray block and enough surrounding area for locating the block and orienting during turns. Generally, topographic maps are used for larger spray blocks, and aerial photos for small blocks. A second factor is that some spray pilots and navigators prefer either maps or photos. Third, photos and maps vary in price and availability. Topographic map series generally are less expensive and are more available for most areas, but good aerial photo coverage is becoming increasingly common. Fourth, the detail present on the map or photo is important. Contour lines on topographic maps can be extremely helpful. However, topographic maps are frequently outdated and often do not show current road networks or clearings. These features are prominent in recent aerial photos as are forest type changes between softwood and hardwood stands.

Guidance Systems

Spray or guide aircraft can be navigated using one of three systems: visual, electronic, or a combination of visual and electronic guidances. Visual guidance can be effective if spray blocks are designed to use easily seen surface features to mark boundaries, if marking devices are used to delineate hard-to-see corners or boundaries, and pilots and navigators prefly difficult spray blocks. The most difficult tasks using visual guidance are to stay on flight lines and to offset the correct distance for the next flight line (Barry 1977). Visual guidance is commonly used in gypsy moth spraying.

Electronic guidance systems are more common in spruce budworm spraying. One reason is that budworm projects have relatively large spray blocks and use bigger aircraft with a navigator or spray teams made up of spray and support aircraft. In contrast, gypsy moth spraying consists of smaller blocks and aircraft with no navigator and smaller teams often with no support aircraft. Spray pilots are so busy flying safely, orienting themselves visually, and turning booms on and off that there is precious little time to operate other instruments.

Electronic systems function via a permanent set of transmitters producing signals (Loran-C), or rely on portable transmitter units that need line-of-sight communication (Transponder or Flying Flagman), or have a self-contained inertial navigation system that relies on an onboard gyroscope (LTN51). In general, these systems are electromechanical in nature, have little human input, are expensive, and require experienced technicians to operate. They are best suited for very large acreages on gentle terrain where flight lines are long and straight and several aircraft can fly in echelon.

Combining visual and electronic guidance may have the most promise. Even with electronic guidance, visual checks are necessary. In case the system breaks down, visual guidance would allow the operation to continue. The weaknesses of visual guidance are not maintaining a straight course within a flight line and offsetting swaths. If these problems can be handled electronically, then turning booms on and off can be accomplished visually.

Conclusions

Guidance is one of the most important factors determining the success (and liability) of operational spray projects. How spray blocks are designed and organized is important. Blocks should be designed based on biological need and ease of treatment. Each spray block should be considered as a set of individual flight lines. The most important aspect for each flight line is easily recognized features to mark beginning and ending points.

Obtain the best possible pilots and guides available! Use the best maps or photos available, and clearly indicate all boundaries, corners, markers, and sensitive areas. Plan ample time to prefly difficult spray blocks to familiarize pilots and navigators with the area. Allow for enough time so that operators of electronic guidance equipment can

perform effectively. Have visual guidance ready in case electronic guidance systems fail.

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Flight Path Recording
Billy F. Tanner

Introduction

The purpose of a flight path recording system is to provide a permanent record of the flight. The data collected is valuable to program managers/supervisors to determine if:

- pesticide application was made in the designated area
- the correct number of passes were applied within the area
- exclusion sites within the area were not treated
- spray was turned on/off at the area boundaries
- application continued from the ending point of the previous load.

Flight Recording Systems

All flight recorders must receive position information from some type of transmitted guidance signal, such as: Loran-C, Omega, Global Positioning Systems, Inertial Navigation Systems, or portable navigation systems such as Del Norte, Maxiran, or others. Some recording systems are designed with the navigation receiver and the flight recorder combined as a unit, while other designs utilize the navigation signal provided by permanent or temporary mounted receivers. Several navigation systems are available and used for flight path recording; however, Loran-C is the most widely used by the general aviation industry.

Understanding Loran-C

Loran is an acronym for "LOng RAnge Navigation," developed for use by our armed forces during World War II. The early units, designed for maritime use, were large and awkward to use. With present-day technology and the development of the semiconductor microprocessor, the Loran-C receiver is small, inexpensive and suitable for installation in aircraft.

Loran-C is a radio navigation system which uses time synchronized pulsed signals from ground transmitting stations spaced several hundred miles apart. The stations are configured in chains of three to five stations which transmit with the same pulse group repetition interval (GRI). Within each chain, one station is designated as master and the remainder as secondaries. Course guidance is generally provided as a linear deviation from the desired track of a Great Circle Course (i.e., the Loran-C signal).

At present, Loran-C is not available throughout the entire United States. Expansion of coverage and improvements in signal integrity are presently being jointly accomplished by the Federal Aviation Administration and the United States Coast Guard.

Weather disturbances (thunderstorms), electrical noises from motors, generators, welding machines, and time-of-day or seasonal variations can cause unwanted interference. The signal may also be distorted by electrical transmission lines, railroad tracks, and mineral deposits in the soil (especially in mountainous terrain). Signal quality and position accuracy will also be influenced by the receiver's geographical position within the Loran-C chain.

Flight Recording

A flight recorder collects data, documenting time, location and events from take-off to landing. A real-time calendar/clock provides year, month, day, date, hour, minute, and second information as a time stamp for the position data and binary function information. Data is stored in a portable electronic memory device.

Computer Analyzer

The computer analyzer (the computer software that runs the program) will provide a flight summary showing totals of distance and time flown, distance and time spray was on, distance and time spray was off, boom pressure and other data. The flight path can be displayed on a PC computer monitor, and/or stored on a diskette or printed copy for a permanent record.

Summary

A flight path path recording system will provide a permanent, accurate record of the flight. This record could prove invaluable in disputes or litigation. The data is available immediately after the flight. The flight can be viewed on the monitor, and a printed copy showing flight path, total time and distance of the flight; total time and distance pesticide was applied; and exact points/locations each time spray was turned on and off.

Listed below are manufacturers of flight recorders and navigation systems widely used in agricultural aviation. They may be contacted for additional information.

Technology Project, Limited
2101 E. Broadway Road, Suite #28
Tempe, AZ 85282
Telephone: 602/966-7834
FAX: 602/966-7834

Del Norte Technology, Inc.
1100 Pamela Drive
PO Box 696
Euless, TX 76039
Telephone: 817/267-3541
FAX: 817/354-5762

Maxiran Corporation, Inc.
5841 North Highway 441
Ocala, FL 32670
Telephone: 904/629-8044
FAX: 904/351-3898

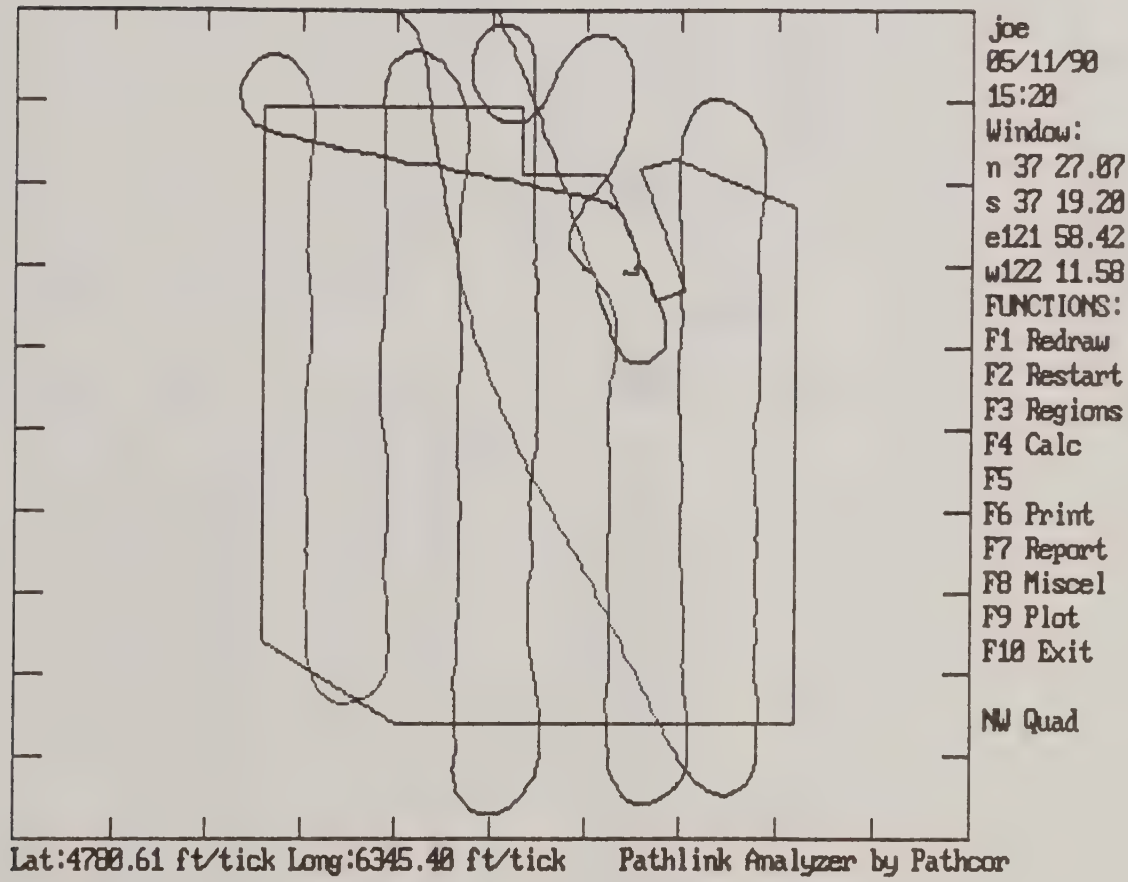

Figure IV-5a. An example of the flight path of an aircraft made during application. The square-looking polygon represents the area being sprayed, and the continuous line represents the track of the spray aircraft.

Table IV-5a. Example of a print-out from a Pathlink unit.

PATHLINK ANALYZER REPORT

Current Date: Mon Dec 10 09:56:58 1990

Flight name: 108
Date of flight: 05/11/90. 15:20

Extents of Flight:

North:	37	30.00
South:	37	18.00
East:	122	0.00
West	122	10.00

SUMMARY OF FLIGHT

SWITCHES

Switch	Status	Lat	Lng	Time(sec)	Distance
3	OPEN	37 24.58	·122 3.17		
4	OPEN	37 24.58	122 3.17		
1	OPEN	37 26.25	122 7.52		
1	CLOSE	37 26.32	122 6.50	333	14.01
1	OPEN	37 25.93	122 5.35		
1	CLOSE	37 19.95	122 5.51	168	6.91
1	OPEN	37 20.18	122 4.32		
1	CLOSE	37 26.33	122 4.44	165	7.10
1	OPEN	37 24.24	122 3.35		
1	CLOSE	37 19.98	122 3.40	120	4.93
1	OPEN	37 20.17	122 2.29		
1	CLOSE	37 24.25	122 2.38	105	4.70
1	OPEN	37 25.37	122 1.30		
1	CLOSE	37 19.86	122 1.38	153	6.35
1	OPEN	37 20.18	122 2.61		
1	CLOSE	37 24.61	122 5.46	135	5.76
1	OPEN	37 25.17	122 3.93		
1	CLOSE	37 24.24	122 3.48	30	1.15

Table IV-5a. Continued.

SUMMARY OF REGIONS:

Region Name: med89.mv
Region Extents:

Maximum Latitude	37	26.15
Maximum Longitude	122	8.19
Minimum Latitude	37	20.28
Minimum Longitude	122	0.85

PATHLINK ANALYZER SUMMARY

Flight Name: joe
Date of flight: 05/11/90, 15:20

Total distance flown: 90.72 mi
Total time flown: 37 min(s) 24 sec(s)
Total distance using switch 1: 50.91 mi
Total distance using switch 2: 0.00 mi
Total distance using switch 3: 90.72 mi
Total distance using switch 4: 90.72 mi
Total distance using no switches: 0.00 mi
Total time using switch 1: 20 min(s) 9 sec(s)
Total time using switch 2: 0 min(s) 0 sec(s)
Total time using switch 3: 39 min(s) 24 sec(s)
Total time using switch 4: 39 min(s) 24 sec(s)
Total time using noswitches: 0 min(s) 0 sec(s)

6. AERIAL SPRAY MODELS: AGDISP AND FSCBG

Milton Teske, John Barry
and Robert Ekblad

Introduction

For the last fifteen years the USDA Forest Service, in cooperation with the U. S. Army, has been pursuing the development of computer models to predict the deposition distribution of aerially released material. Computer simulation models provide a tool for planning, conducting and evaluating safe and effective use of pesticides to manage gypsy moth and other forest pests.

There are two computer models maintained by the USDA Forest Service that predict the deposition, dispersion and drift of pesticides. These are the AGricultural DISPersal (AGDISP) and Forest Service Cramer-Barry-Grim (FSCBG) models. A more complete description of the AGDISP model may be found in Bilanin et al. 1989, and the FSCBG model, in Barry et al. 1991.

The USDA Forest Service is interested in understanding the behavior of aerial spray releases from the time the spray is released from the aircraft until it is deposited in the canopy or on the ground, or is dispersed to airborne concentrations that are environmentally insignificant. Mathematical spray dispersion simulation models are useful in determining the interactions of the many interrelated factors affecting spray operations.

Model Uses

There are several uses or applications that the AGDISP and FSCBG models are particularly well-suited for. These include the following:

<u>Requirement Analyses and Planning Aerial Spray Operations</u>

- Selecting an appropriate spray delivery system -- matching aircraft with atomizers.
- Selecting the proper atomization -- nozzles and atomizers may be adjusted or adapted to generate a specific drop size distribution.
- Deciding on spray application rate, formulation, release height and swath width.
- Selecting spray-on and spray-off points.
- Developing specifications for application contracts.
- Developing operations plan.

<u>Conducting Aerial Spray Operations</u>

<u>Post Spray Evaluation of Aerial Spray Operations</u>

- Comparing model predictions with observations for model improvement.
- Identifying opportunities to improve, update and enhance model.
- Assisting in preparation of project report.
- Evaluating what was right and what went wrong.
- Critiquing spray operation.
- Evaluating contractor performance.

<u>Documentation of Aerial Spray Operations</u>

Documenting the planning, operation and evaluation process for use in potential lawsuits.

<u>Research and Development</u>

- Designing field tests.
- Reducing the trial-and-error approach to field testing.
- Evaluating formulations based on their physical properties.
- Identifying parameters needing further research.

<u>Regulatory</u>

Establishing criteria for regulating aerial use of pesticides.

AGDISP Model

AGDISP is a program that includes simplified models for aircraft wake and ambient turbulence effects (including wing tip and rotor tip vortices, helicopter downwash and forward flight, cross wind, vortex decay and drop evaporation). AGDISP tracks the motion of a group of similar sized particles or drops released into the atmosphere from specified nozzle locations. Similar sized drops are combined into a drop size distribution (made up of up to 16 drop sizes) to generate the spray droplet cloud. The novel feature in AGDISP is that the dispersion of the group of similar sized drops resulting from turbulent fluctuations in the atmosphere is quantitatively computed as the spray droplet cloud descends toward the ground. Everything coming from the nozzles can be accounted for.

The development of the AGDISP technology was made technically feasible by research directed at understanding the physics of vortex wakes behind aircraft. This research was stimulated by the introduction of the jumbo jetliner in the 1960s, and the suspected hazard to other aircraft associated with the generated vortex wake, particularly on take-off or landing. A simple vortex wake model, and the subsequent development of a closure technique to recover the effect of atmospheric turbulence on the variance of the spray material about its mean trajectory, lead to the development of AGDISP (Bilanin, Teske and Morris 1981). Later, extensive enhancements to the model have brought it to its present 6.0 version level (Teske 1990).

FSCBG Model

FSCBG is a program that takes the near-wake results of AGDISP and predicts downwind dispersion including drift and the effects of evaporation, meteorology, canopy penetration, and ground and canopy deposition. FSCBG includes: (1) an analytic dispersion model that handles multiple line sources oriented in any direction to the wind; (2) an evaporation model that predicts the change in size of falling spray drops that are either totally volatile or a mixture of volatile and nonvolatile components; (3) an analytic canopy penetration model that estimates the fraction of drops intercepted by a forest canopy; (4) the AGDISP near-aircraft wake model that simulates detailed effects on each drop size in the released spray; (5) a completely rewritten user interface; and (6) extensive presentation graphics for interpretation of results.

Simplified aerial line source models developed for the U.S. Army were first applied in the early 1970s to determine optimum swath widths and application rates for use in pilot tests of insecticides under consideration at that time for control applications in western forests (Cramer et al. 1972). The implications of these early efforts in the use of mathematical models to improve the planning, conducting and subsequent analyzing of spray program operations and results lead to the development of the CBG model. A first reported application of this technology (Waldron 1975) estimated the amount of spray material needed to control an outbreak of spruce budworm. Continued success in simulating field experiments lead to the development of FSCBG (Dumbauld, Bjorklund and Saterlie 1980). The later inclusion of AGDISP into FSCBG (Bjorklund, Bowman and Dodd 1988) and significant further enhancements to the model have brought it to its present 4.0 version level (Teske and Curbishley 1991).

Input Requirements

The information needed to exercise either model includes the following:

- Meteorological conditions anticipated during the spray mission (such as ambient temperature, relative humidity, wind speed and direction).
- Aircraft information (including weight, wing span, flight speed, spray release height).
- Nozzle information (number of nozzles, type of nozzle, locations on boom, flow rate of material through nozzles).
- Spray material information (composition, drop size distribution, volatile fraction).
- Canopy information (height of canopy, general shape, stand density: stems per acre).
- Mission scenario (number of aircraft passes, length of these passes, direction).

This information must be assembled (or deduced or assumed) before model simulation is possible. The models themselves are directed towards a prediction of the behavior of the spray material after it is released from the nozzles. Drop size distributions give the mass distribution of material as it is atomized by the nozzle. Drops containing volatile materials (such as water) begin to evaporate immediately upon entering the atmosphere, with the local temperature and relative humidity determining the rate of evaporation. The presence of the aircraft wake (with its vortical structure) may move material to unanticipated locations. Ambient winds superimpose additional horizontal velocity vectors on the released spray material. Canopy deposition strips spray material and prevents nonvolatile components from reaching the ground. Every aspect of the spray process is affected by the strength and size of atmospheric and aircraft-generated turbulence. All of these fundamental features are modeled in AGDISP and FSCBG.

Table IV.6a summarizes the inputs needed to run AGDISP. AGDISP is driven by an input file that identifies input values by specific card numbers. Auxiliary programs provide interactive creation/editing of the input file, screen presentation of model predictions, and printer copies of the output (Teske 1990). AGDISP runs on MS-DOS based personal computers and the USDA Forest Service Data General computer network. A version of AGDISP also runs with SwathKit, an imaging analyzer used to assess deposit cards. An example of the drop trajectory plot and ground deposition comparison are shown in Figures IV-6a and IV-6b

Table IV-6b summarizes the inputs needed to run FSCBG. FSCBG is a menu-driven program that interacts with the user to set up the input conditions, save them for later re-initializing, run the simulation, and present the results in plot format on the screen. Screen dump routines are then used to transfer results to an attached printer. FSCBG also runs on MS-DOS based personal computers and the USDA Forest Service Data General computer network. An example of the deposition contour plot and data agreement are shown in Figures IV-6c and IV-6d.

Model Evaluations

Both AGDISP and FSCBG have undergone extensive field validation studies. These comparisons may be seen in the references Teske 1988, 1989a and 1989b for AGDISP; and Boyle et al. 1975, Rafferty et al. 1989, and Teske et al. 1990 for FSCBG.

AGDISP is now at modification level 6.0 with recent inclusion of the ability to predict up to 16 drop sizes in one run, assemble these results for plotting, and compute the lane separation between parallel swaths using a coefficient of variation argument. FSCBG is at modification level 4.0 with a recent rewriting of its user interface, and extensive expansion of its graphics capability. Any person wishing to acquire a copy of either model and its documentation may contact any of the authors or by writing USDA Forest Service, Director, Forest Pest Management, Washington D. C. Training sessions on the use of the models are sponsored by the respective model user groups. For information, contact the first author.

Table IV-6a. AGDISP Inputs.

Input Category	Data Description
Terrain	Local ground slope at point of spray release
Aircraft characteristics	Type (ground sprayer, helicopter, fixed-wing) Semispan (rotor radius) Release height Flight speed Vertical distance between wings (biplane) Weight Blade rotation rate (helicopter)
Atmospheric conditions	Mean wind speed, wind direction and altitude of measurement Surface roughness Wind speed as a function of height
Engine characteristics	Thrust, exit radius, position on aircraft (jet) Wing planform, shaft rpm, radius, position on aircraft (propeller)
Turbulence	Background atmospheric level Vortex circulation decay factor
Canopy characteristics	Plant area fraction as a function of height Capture efficiency
Nozzle placement	Number and location in three directions Initial drop diameters Specific gravity of released material
Evaporation	Wet bulb temperature difference Volatile fraction of released material

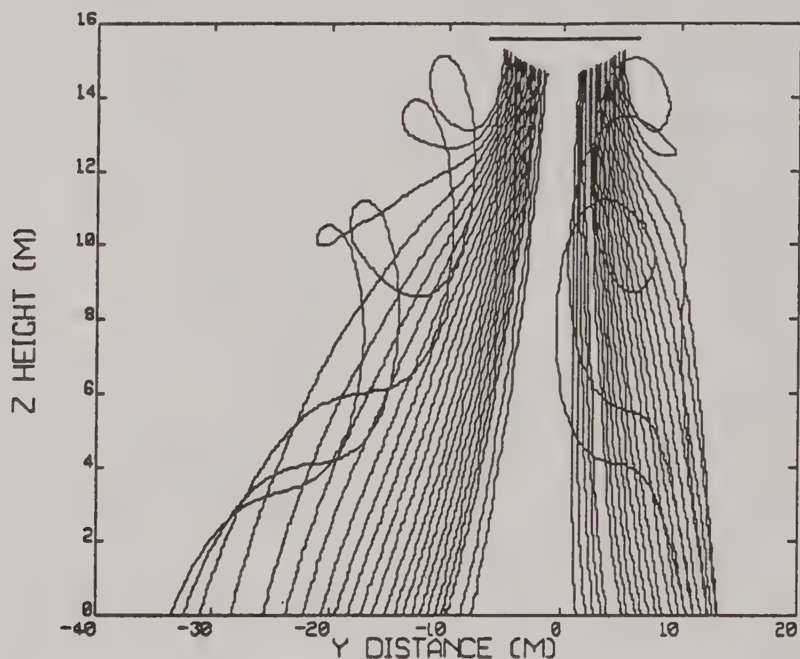

Figure IV-6a. Predicted spray drop trajectories for 171 micron drops released into the wake of an AgTruck (Teske 1988). The outermost drops are most influenced by the wing tip vortices. A slight right-to-left crosswind exists in this example. The double thick horizontal line near the top of the plot is a representation of the aircraft wing position and the 47 nozzles in the simulation.

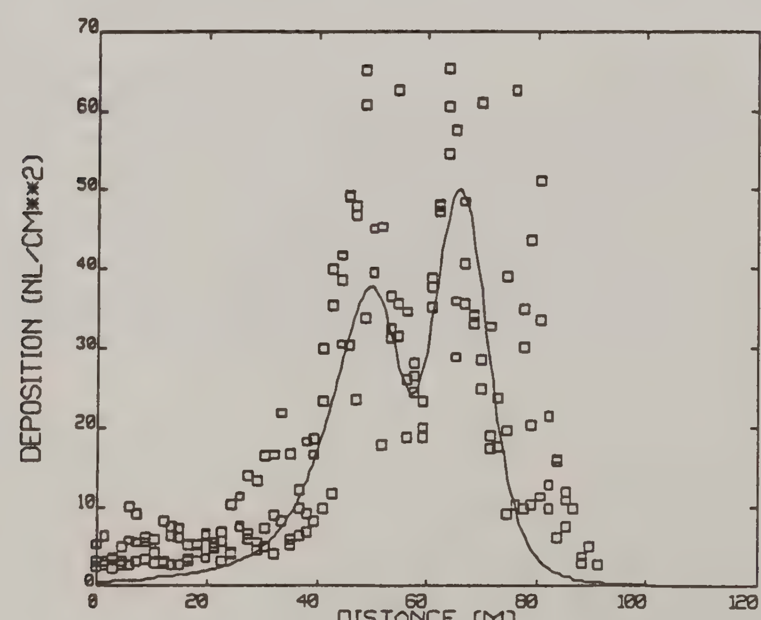

Figure IV-6b. Ground deposition predictions compared with data (Teske 1988).

Table IV-6b. Inputs to the FSCBG model.

Input Category	Data Description
Aircraft wake description	Semispan (rotor radius) Release height Vertical distance between wings (biplane) Flight speed Weight Blade rotation rate (helicopter) Engine thrust, exit radius, position on aircraft (for jet engines) Wing planform, shaft rpm, position on aircraft (for propellers) Nozzle placement
Source characteristics	Specific gravity of released material Drop size distribution Volatile fraction
Source geometry	Flight lines: lengths and directions relative to receptor grid Emission rate (swath width)
Meteorology	Pressure Temperature, relative humidity, wind speed and direction as a function of height Radiation index Mixing depth Turbulence standard deviation (background turbulence level) Vortex circulation decay factor
Canopy penetration	Tree shape as a function of height Stand density (stems per acre) Vegetative element size Probability of penetration
Receptor geometry	Horizontal X-Y receptor grid locations

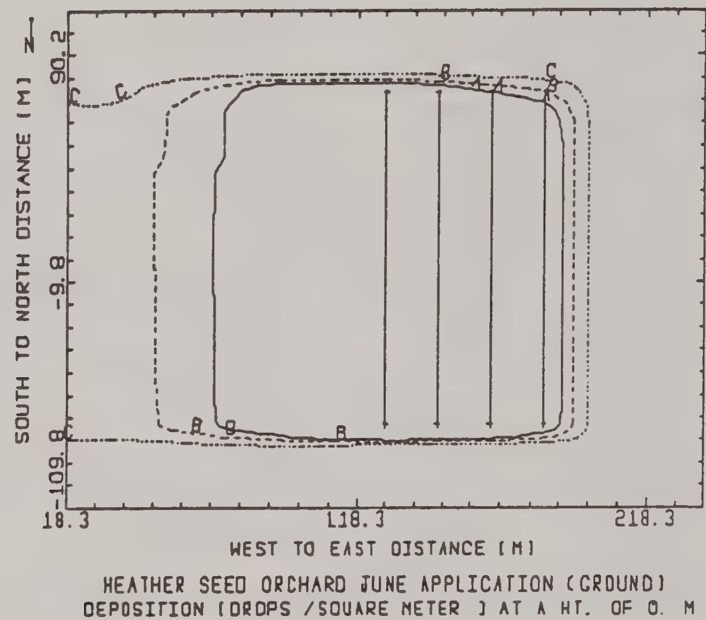

Figure IV-6c. Example of drift prediction with the FSCBG model. Release height is 50 feet above the open ground in four flight lines (shown as the four solid vertical lines). A cross wind of 5 miles per hour is blowing from right to left across the spray area. The deposition curves are 10, 5 and 1 drops per square centimeter.

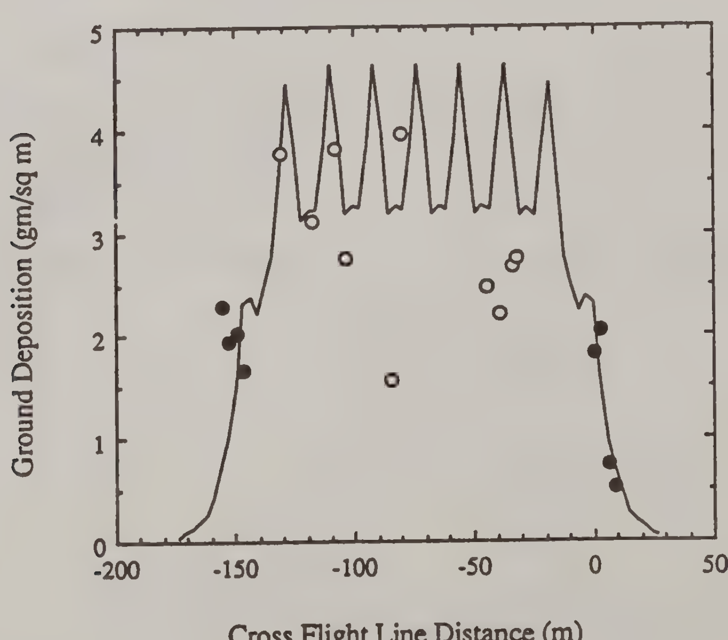

Figure IV-6d. Model predictions of deposition (solid curve) versus observed deposition (open and closed circles) from an operational aerial treatment of a seed orchard (Teske et al. 1990).

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APPENDIX A

GLOSSARY OF TERMS

Adiabatic process	A thermodynamic process in which no heat passes into or out of the air mass. As air rises, pressure on it decreases and in response it expands. The act of expansion to encompass its new dimensions requires an expenditure of energy; since temperature is a measure of internal energy, this use of energy makes its temperature drop, and the drop in temperature is 10°C for each kilometer of ascent.
Application rate	The total quantity of material applied per acre. It is distinguished from dose rate which is the amount of active ingredient per unit area.
Calibration	Calculating and obtaining a desired flow rate from a spray system.
Characterization	The evaluation of spray swath including an assessment of swath width, VMD and drop densities across the swath.
COV	Coefficient of variation is a relative measure of variation equal to the standard deviation divided by the mean.
D-max	A general method of estimating and evaluating spray droplet sizes. The procedures for determining the VMD using the D-max method are described on pp. 117-118.
Dose rate	The amount of active ingredient of insecticide per unit area.
Drift	The aerial movement of a material to a place other than the target. Drift results from spray droplets floating or being driven off-site.
Inversion	Reversal of the normal temperature change with altitude, where temperature rises as altitude increases.
Lane separation	The distance between successive flight patterns.
Micron	One millionth of a meter. One micron (µm) equals .00003937 inches.
Neat	The use of an insecticide in its undiluted state without the addition of water or another diluent.
NMD	Number median diameter or Dv.5. The droplet size that divides the spray in half on the basis of droplet numbers. Half of the droplets will be smaller than the NMD size, and half will be larger.
Nozzle	Any device through which liquid is emitted, broken up into droplets, and dispersed.
Relative humidity	The amount of water in the air expressed as a percentage of the maximum that the air could hold at a given temperature.
Rotary atomizer	A spray unit which forms droplets using rotation. The rotating atomizers used on aircraft are usually rotating cages or rotating cylinders. They are either driven by wind using the slipstream or by electric motors.
Sedimentation Velocity	The maximum speed of fall of a droplet relative to the velocity of the surrounding air. This speed is a function primarily of droplet diameter.
Slipstream	Propeller slipstream is the spiral core of air around the fuselage from the propeller. It can disrupt the spray swath.
Spread factor	A constant used to convert stain size measured on a card surface to actual droplet size causing that stain. It is conventional to express spread factors as droplet size divided by stain size. Thus, a droplet which gives a stain twice as wide as its original size has a spread factor of 0.5. However, the same relationship can also be expressed as stain size divided by droplet size, giving a spread factor of 2. Accurate spread factors are never given as a size coefficient (conversion factor),

because the relationship of a droplet to its stain varies with droplet size. Rather they are given as a polynomial expression as drop = a + b X stain + c X stain^2, values a,b, and c are constants.

Stain analysis	The measurement of droplet stains providing data on droplet density, droplet sizes, percentage of area covered and volume of deposit.
Sticker	Ingredient added to spray mixture to improve its adherence to plant surfaces.
Swath width	The width of the deposition of a spray swath on the ground or target. Effective swath can be considered as the portion of the total swath that receives at least the minimum dosage that will reduce the pest population.
Turbulence	The irregular motion of the air indicated by gusts and lulls.
Variable	Controls the flow to Micronair rotating atomizer by means of restrictor unit an orifice plate with a number of holes of different sizes. (VRU)
Viscosity	Internal fluid resistance of a substance caused by molecular attraction, which makes it resist a tendancy to flow. A viscous fluid is thick, slurry, and sticky.
Volatility	A measure of a liquid's physical capacity to vaporize. A volatile liquid will quickly evaporate.
VMD	Volume median diameter or Dv.5. A measure of droplet sizes. The droplet size that divides the spray volumes in half, 50 percent above the Dv.5 and 50 percent below.
Vortices	The passage of both fixed wing and helicopters at cruise speeds (greater than 45 mph) leaves pairs of rolling air masses in the air behind the aircraft. These vortices are shed from just inbound of the tip of all lifting aerofoil surfaces. Vortices are induced by the air movement and pressure patterns needed to maintain lift over the wing surface.
Wettable Powder	Pesticide formulation of toxicant mixed with inert dust and a wetting agent that mixes readily with water and forms a short-term suspension
Work rate	Production rate of a spraying aircraft, usually expressed in terms of acres per hour.

APPENDIX B

CONVERSION TABLES AND DEFINITIONS RELATED TO AERIAL APPLICATION TECHNIQUES

METRIC MEASURES AND WEIGHTS

Linear measures	Symbol	Eqivalent units
kilometer	km	1,000 m
meter	m	1,000 mm
decimeter	dm	100 mm
centimeter	cm	10 mm
millimeter	mm	1,000 µm
micrometer	µm	0.001 mm

Capacity	Symbol	Equivalent units
hectolitre	hl	100 l
litre	l	10 dl(dm^3)
decilitre	dl	0.1 l
millilitre	ml(cm^3)	0.001 l
microlitre	µl(mm^3)	10^{-6} l

Area	Symbol	Equivalent units
sq kilometer	km^2	1,000,000 m^2
hectare	ha	10,000 m^2
are	a	100 m^2
sq meter	m^2	100 dm^2
sq decimeter	dm^2	100 cm^2
sq centimeter	cm^2	100 mm^2
sq millimeter	mm^2	1,000,000 μm^2
sq micrometer	μm^2	10^{-6} mm^2

Weight	Symbol	Equivalent units
metric ton	t	1,000 kg
kilogram	kg	1,000 g
gram	g	1,000 mg
milligram	mg	1,000 µg
microgram	µg	1,000 ng
nanogram	ng	10^{-3} µg

Volume	Symbol	Equivalent units
cu meter	m^3	1,000 dm^3
cu decimeter	dm^3	1,000 cm^3
cu centimeter	cm^3	1,000 mm^3
cu millimeter	mm^3	10^9 μm^3
cu micrometer	μm^3	10^{-9} mm^3

Powers of 10			
10^1 =	10	10^{-1} =	0.1
10^2 =	100	10^{-2} =	0.01
10^3 =	1,000	10^{-3} =	0.001
10^4 =	10,000	10^{-4} =	0.0001
10^5 =	100,000	10^{-5} =	0.00001
10^6 =	1,000,000	10^{-6} =	0.000001

Metric prefixes (SI*)

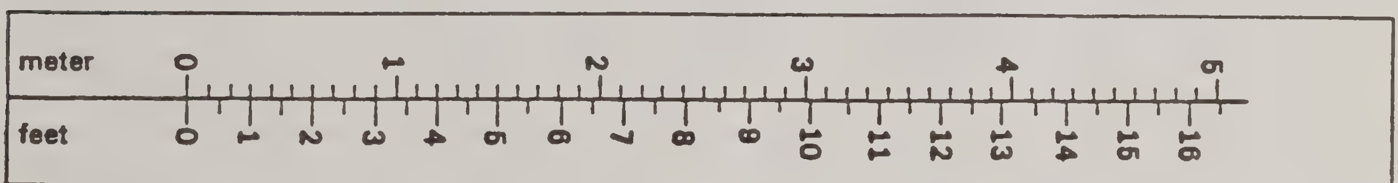
Prefix	Symbol	Meaning (in the USA)	In other countries	Multiplication factor
exa	E	one quintillion times	trillion	1 000 000 000 000 000 000 = 10^{18}
peta	P	one quadrillion times	thousand billion	1 000 000 000 000 000 = 10^{15}
tera	T	one trillion times	billion	1 000 000 000 000 = 10^{12}
giga	G	one billion times	millard	1 000 000 000 = 10^9
mega	M	one million times		1 000 000 = 10^6
kilo	k	one thousand times		1 000 = 10^3
hecto	h	one hundred times		100 = 10^2
deka	da	ten times		10 = 10
deci	d	one tenth of		0.1 = 10^{-1}
centi	c	one hundreth of		0.01 = 10^{-2}
milli	m	one thousandth of		0.001 = 10^{-3}
micro	µ	one millionth of		0.000 001 = 10^{-6}
nano	n	one billionth of	millardth	0.000 000 001 = 10^{-9}
pico	p	one trillionth of	billionth	0.000 000 000 001 = 10^{-12}
femto	f	one quadrillionth of	thousand billionth	0.000 000 000 000 001 = 10^{-15}
atto	a	one quintillionth of	trillionth	0.000 000 000 000 000 001 = 10^{-18}

*Système internationale d'Unité

Concentrations	Symbol	Weight/volume w/v	Weight/weight w/w
per cent	%	10 g/l = 1 kg/ 100 l	10 g/kg = 1 kg/ 100 kg
per mille	‰	1 , g/l = 1 kg/1,000 l	1 g/kg = 1 kg/1,000 kg
part per million	ppm	γ µ/ml = 1 mg/l	1 µg/g = 1 mg/kg
part per billion (US)	ppb		1 ng/g = 1 µg/kg

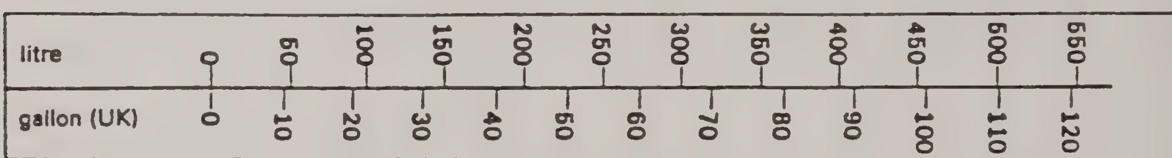
CONVERSION TABLES

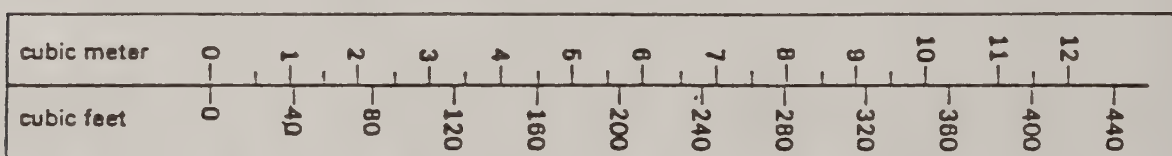
Linear measure	Metric units		Anglo-Saxon units		
1 unit =	kilometer	meter	mile	yard	foot
km	1.000	1,000.000	0.621	1,093.600	3,281.000
m	0.001	1.000	-	1.094	3.281
mile	1.609	1,609.350	1.000	1,760.000	5,280.000
yd	-	0.914	-	0.333	3.000
1 unit =	meter	centimeter	yard	foot	inch
m	1.000	100.000	1.094	3.281	39.370
cm	0.010	1.000	0.011	0.033	0.394
yd	0.914	91.440	1.000	3.000	36.000
ft(')	0.305	30.480	0.333	1.000	12.000
in(")	0.025	2.540	0.028	0.083	1.000



Area	Metric units			Anglo-Saxon units			
1 unit =	sq meter		sq centimeter	sq rod	sq yard	sq foot	sq inch
m²	1.000		10,000.000	0.040	1.197	10.765	-
cm²	-		1.000	-	-	-	0.155
sq rod	25.293		25,293.000	1.000	30.250	272.250	-
sq yard	0.836		8,361.274	0.033	1.000	9.000	1,296.000
sq ft	0.093		929.030	0.004	0.111	1.000	144.000
sq in	-		6.452	-	0.077	0.007	1.00
acre	4,046.868		-	760.000	4,860.000	43,560.000	-
1 unit =	hectare	km²	m²	acre	sq mile		
hectare	1.000	0.010	10,000.000	2.471	0.004		
km²	100.000	1.000	1,000,000.000	247.105	0.386		
m²	-	-	1.000	-	-		
acre	0.405	0.004	4,046.868	1.000	0.002		
sq mile	258.998	2.590	2,589,983.604	640.000	1.000		

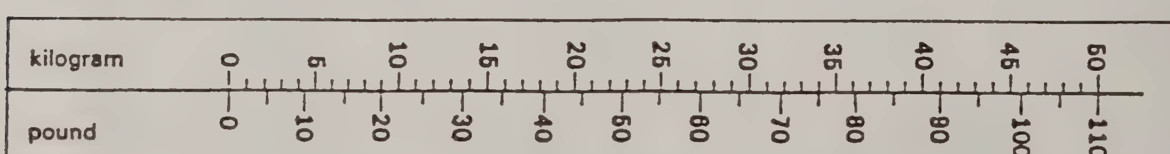
Liquid measures	Metric unit	US units				UK units			
1 unit =	litre	gallon	quart	pint	fluid ounce	gallon	quart	pint	fluid ounce
litre	1.000	0.264	1.057	2.113	33.814	0.220	0.880	1.760	35.196
US bushel	35.239	9.310	37.251	74.501	-	7.752	31.020	62.040	-
US gal	3.785	1.000	4.000	8.000	128.000	0.833	3.332	6.661	133.223
US qt	0.946	0.250	1.000	2.000	32.000	0.208	0.833	1.666	33.786
US pt	0.473	0.125	0.500	1.000	16.000	0.104	0.416	0.833	16.653
US fl oz	0.029	~0.008	0.031	0.062	1.000	~0.006	0.026	0.052	1.041
UK bushel	36.368	9.608	38.444	76.864		8.000	32.000	64.000	-
UK gal	4.546	1.201	4.805	9.608	153.722	1.000	4.000	8.000	160.000
UK qt	~ 1.136	0.300	1.201	2.402	39.207	0.250	1.000	2.000	40.000
UK pt	0.568	0.150	0.600	1.201	19.215	0.125	0.500	1.000	20.000
UK fl oz	0.028	~0.008	0.030	0.060	0.961	~0.006	0.025	0.050	1.000





Weight	Metric unit	Anglo-Saxon unit	US units		UK units	
1 unit =	kilogram	pound	short ton	short hundred-weight	long ton	long hundred-weight
ton (metric)	1,000.000	2,202.643	1.102	22.046	0.984	19.684
kg	1.000	2.204	~0.001	0.022	~0.001	0.020
ton (long ton)	1,016.050	2,240.000	1.120	22.400	1.000	20.000
ton (short ton)	907.185	2,000.000	1.000	20.000	0.893	17.857
cwt (UK)	50.802	112.000	0.056	1.120	0.050	1.000
cwt (USA)	45.359	100.000	0.050	1.000	0.045	0.893
lb	0.454	1.000	<0.001	0.010	<0.001	~0.009

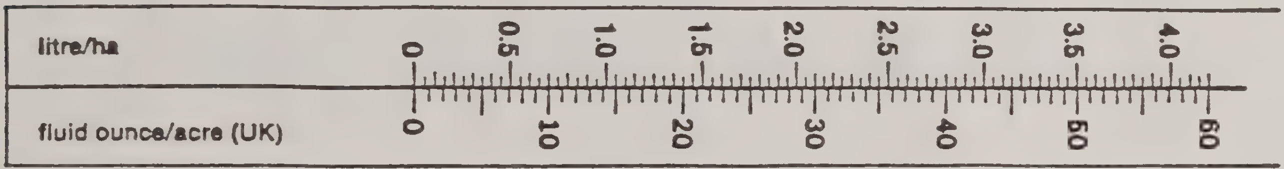
1 tonne = 1 metric ton in literature (UK)

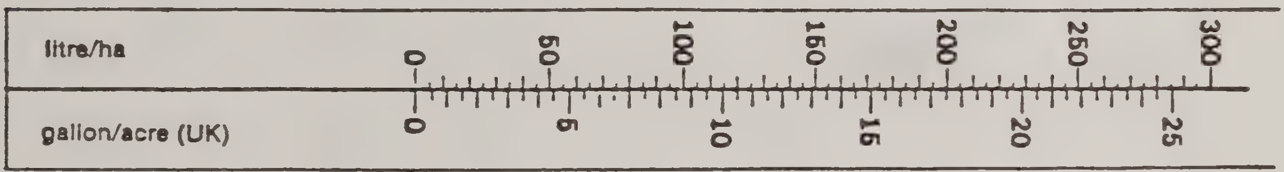


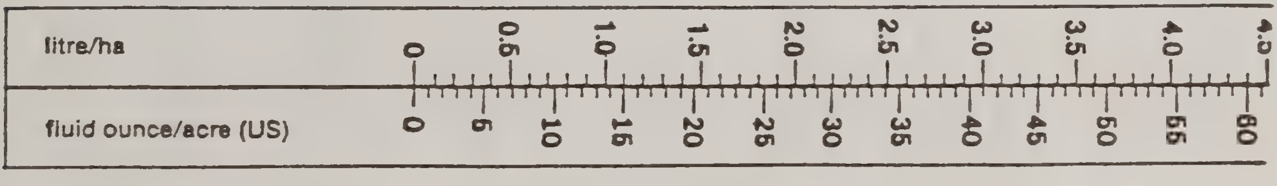
Volume		
1 m³	=	35.315 cu ft
1 m³	=	1.308 cu yard
1 cm³	=	0.061 cu inch
1 yard³	=	0.765 m³
1 ft³	=	0.028 m³
1 in³	=	16.387 cm³

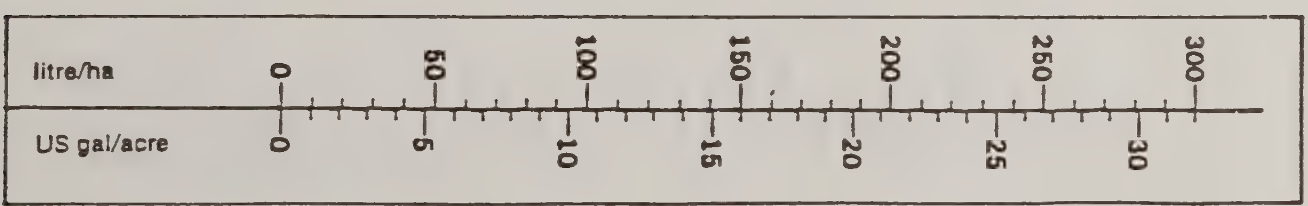
Weight	Metric units		Anglo Saxon units	
1 unit =	kilogram	gram	pound	ounce
kg	1,000	1,000.000	2.205	35.273
g	0.001	1.000	~0.002	0.035
lb	0.454	453.592	1.000	16.000
oz	0.028	28.350	0.062	1.000

Volume per area	Metric unit	US units			UK units		
1 unit =	litre hectare	gallon/ acre	pint/ acre	fluid ounce/ acre	gallon/ acre	pint/ acre	fluid ounce/ acre
ml/ha	0.001	-	-	0.0137	-	-	0.0142
litre/ha	1.000	0.107	0.855	13.684	0.089	0.712	14.243
US gal/acre	9.353	1.000	8.000	128.000	0.833	6.661	133.223
US pint/acre	1.169	0.125	1.000	16.000	0.104	0.833	16.653
US fl oz/acre	0.073	~ 0.008	0.062	1.000	~0.006	0.052	1.041
UK gal/acre	11.233	1.201	9.608	153.722	1.000	8.000	160.000
UK pint/acre	1.404	0.150	1.201	19.215	0.125	1.000	20.000
UK fl oz/acre	0.070	~0.008	0.060	0.961	~0.006	0.050	1.000



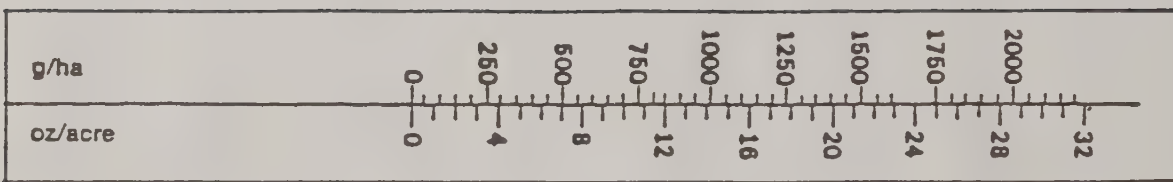


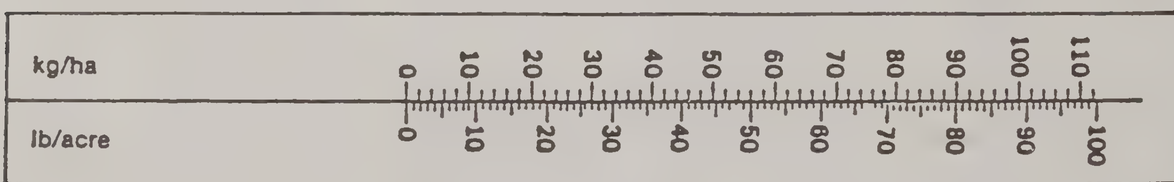




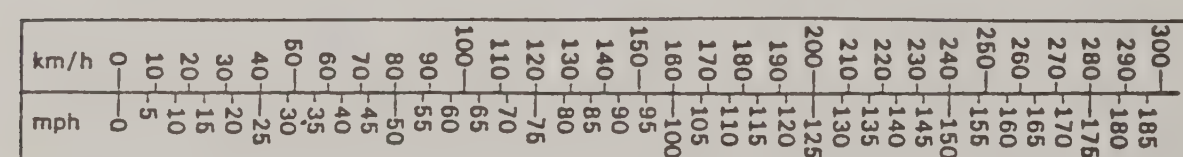
Weight per area	Metric units	Anglo-Saxon units	
1 unit =	kilogram/ hectare	pound/ acre	ounce/ acre
kg/ha	1.000	0.892	14.275
lb/acre	1.121	1.000	16.000
oz/acre	0.070	0.062	1.000
cwt/acre	125.552	112.000	1,792.000
kg/feddan	2.380	2.123	33.875
lb/feddan	1.079	0.962	13.731

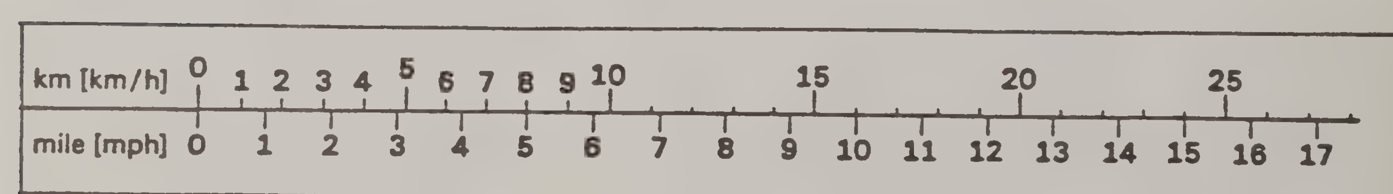
Weight per area		
1 $\mu g/cm^2$	=	100 g/ha
1 g/ha	=	0.01 $\mu g/cm^2$
1 lb/100 sq ft	=	488.172 kg/ha
1 lb/sq yd	=	0.543 kg/m^2
1 kg/m^2	=	0.205 lb/sq ft
1 kg/m^2	=	1.842 lb/sq yd





Speed per time unit	Metric units			Anglo-Saxon units		
1 unit =	kilometer/ hour	meter/ minute	meter/ second	mile/ hour	feet/ minute	knot int.
km/h	1.000	16.667	0.278	0.621	54.682	0.540
m/min	0.060	1.000	0.017	0.037	3.208	0.032
m/s	3.600	60.000	1.000	2.237	196.850	1.944
mph	1.609	26.817	0.447	1.000	88.000	0.869
ft/min	0.018	0.305	~0.005	0.011	1.000	~0.010
knot int.	1.852	30.867	0.514	1.151	101.269	1.000





APPENDIX C

ASAE CALIBRATION AND DISTRIBUTION PATTERN TESTING OF AGRICULTURAL AIRCRAFT APPLICATION EQUIPMENT

ASAE Standard: ASAE S386.2

T CALIBRATION AND DISTRIBUTION PATTERN TESTING OF AGRICULTURAL AERIAL APPLICATION EQUIPMENT

ASAE

STANDARD

Adopted and published by

American Society of Agricultural Engineers

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T CALIBRATION AND DISTRIBUTION PATTERN TESTING OF AGRICULTURAL AERIAL APPLICATION EQUIPMENT

Developed by the ASAE Agricultural Chemicals Application Committee; approved by the ASAE Power and Machinery Division Standards Committee; adopted by ASAE as a Tentative Standard June 1977; reconfirmed December 1978, December 1979, December 1980, December 1981; revised and reclassified as a full Standard January 1983; revised February 1988.

SECTION 1—PURPOSE AND SCOPE

1.1 This Standard establishes uniform procedures for measuring and reporting application rates and distribution patterns from agricultural aerial application equipment.

1.2 The procedures covered deal with both fixed and rotary wing aircraft equipped with either liquid or dry material distribution systems.

1.3 These procedures and the statistics reported do not imply optimum conditions for satisfying biological requirements.

SECTION 2—DEFINITIONS

2.1 For the purpose of this Standard the following definitions shall apply:

2.1.1 **Application rate:** Application rates are as defined in ASAE Standard S327, Terminology and Definitions for Agricultural Chemical Application.

2.1.2 **Deposit rate:** Deposit rates are as defined in ASAE Standard S327, Terminology and Definitions for Agricultural Chemical Application.

2.1.3 **Single-pass application:** An application method where the aircraft applies one swath over the sample line.

2.1.4 **One-direction application:** An application method where successive adjacent swaths are made in the same direction of travel (racetrack application). This method produces a right-on-left wing overlap pattern.

2.1.5 **Progressive application:** An application method where the aircraft applies adjacent swaths but travels in alternate directions for each swath (back and forth application). This method produces a right-on-right wing overlap alternately with a left-on-left wing overlap pattern.

2.1.6 **Swath spacing:** The lateral distance between the aircraft centerlines for overlapping broadcast applications.

2.1.7 **Effective swath width:** The swath spacing that will produce acceptable field deposition uniformity for intended application.

2.1.8 **Nozzle orientation:** The angle of spray discharge from the nozzles measured relative to the local airflow in flight. A nozzle orientation of 90 deg denotes spray discharge perpendicular to the direction of the local airflow while a nozzle orientation of 0 deg denotes spray discharge that is parallel and to the rear.

2.1.9 **Indicated airspeed:** The speed as indicated by the airspeed indicator of the aircraft in flight.

SECTION 3—TEST CONDITIONS

3.1 The physical characteristics of the liquid or dry material have an effect on the application rate and the distribution patterns. If inert test solutions or materials are substituted for the material to be applied, they must have physical characteristics similar to those of the material to be applied.

3.2 The distribution equipment to be tested should be in good mechanical condition and properly equipped and adjusted for the type of application to be simulated.

3.3 The tests should be conducted when wind speeds are less than 16 km/h (10 mph) measured at 2.5 m (8.2 ft) above the land surface or crop canopy. The distribution pattern test flights should be made parallel to or within 15 deg of the direction of the wind to minimize errors due to crosswinds. Output rate test flights should be made considering both headwind and tailwind components to minimize the effects of wind velocity on the ground speed of the aircraft.

3.4 The following provisions will help assure that the tests will be carried out in a safe and efficient manner.

3.4.1 **Test site.** The test site should be selected where the aircraft can have a minimum unobstructed approach (from power lines, buildings, trees, fences, etc.) and departure distance to and from the sample line of 300 m (1 000 ft). The site should allow orientation of a 30 m (100 ft) sample line at a right angle to the prevailing wind. The site should be located in an area where there is a minimum of other flying aircraft. Local airport and/or FAA authorities should be informed of scheduled activity so that proper notification can be made to other aircraft operating in the immediate area.

3.4.2 **Toxic materials.** When toxic materials are used, all safety precautions prescribed by the manufacturer and regulating authorities for handling, loading, application and disposal shall be observed.

3.4.3 **Residues.** Distribution equipment previously used in field applications should be cleaned and flushed of any residue prior to starting the test procedure. Special cleaning agents may be necessary to neutralize previously used pesticides or additives.

3.4.4 **Safety precautions.** Prior to initiating any tests, the pilot and all test site personnel shall be thoroughly briefed on test procedures. At the flight test area, all personnel shall stand clear of the aircraft flight path. Special safety precautions shall be observed when stationary aircraft tests are conducted with the engine running to prevent serious injury by a moving propeller or rotor. If toxic materials are used, personnel should remain clear of application and drift areas, and appropriate precautions shall be taken to prevent contamination of test personnel and test site.

SECTION 4—TEST DESCRIPTION AND PROCEDURE

4.1 A test shall consist of four parts: (1) determination of the output rate from the aircraft, (2) determination of the swath distribution pattern by measurement of the applied materials from suitable collectors, (3) determination of the maximum effective swath width and the corresponding uniformity of distribution for overlapped swaths and, (4) determination of application rate. Each part of the test shall be replicated to account for random variation.

4.2 Output rate test

4.2.1 **Liquid materials.** The output rate should be determined by measuring the amount of liquid discharged from the tank for a measured time interval while the aircraft is operated under normal conditions. The time interval should be sufficient to permit accurate measurement and minimize errors due to turning the system on and off (at least 30 s) and should be measured to the nearest 0.1 s. The amount of liquid used shall be measured by either refilling the tank to the initial level or by measuring the amount remaining in the tank and subtracting from the initial amount. Care must be taken to position the aircraft in exactly the same position on a level surface for the measurement and refilling operations. Measurement precision should be ± 1% of the amount output. These data may also be used to calibrate flow meters that may already be a part of the system. If the liquid dispersal system can be operated normally with the aircraft stationary, the test can be accomplished without actually flying the aircraft. Output rate shall be expressed in L/min (gpm).

4.2.2 **Dry materials.** The output rate should be determined by measuring the amount of material discharged from the hopper over a given time interval while in normal flight. The time interval length and measurement precision specified in paragraph 4.2.1 shall also

apply to the determination of the output rate for dry materials. The test shall be run with the aircraft hopper filled to at least 25% of capacity. Output rate shall be expressed in kg/min (lb/min).

4.3 Swath distribution pattern test. This test shall be accomplished by flying the aircraft over the center of a target sample line placed at a right angle to the line of flight. The center of the sample line shall be marked, and any deviation of the aircraft line of flight from the sample line center shall be noted. The sample line may be placed on the land surface, at crop height or at any other height consistent with the purpose of the test. The aircraft shall be flown at a height suited to the type of material applied and the purpose of the application. Actual aircraft height shall be measured and recorded. The airspeed shall be that recommended for the particular type of application, and the aircraft should be flown straight and level through the entire test course. The sample line should extent beyond the ends of the pattern being tested. Ordinarily, the sample line will be oriented so that the aircraft will be flying directly into the wind to minimize the effects of crosswind on the distribution pattern. However, once an acceptable distribution pattern has been obtained, a crosswind series may be run to establish the distribution pattern under this operating condition. Ambient temperature, humidity, horizontal wind speed and wind direction (with respect to the direction of flight) shall be measured at a height of 2.5 m (8.2 ft) above the sample line. The dispersing equipment in the aircraft shall be turned on at least 200 m (660 ft) prior to crossing the sample line and shall continue operating the same distance beyond. For tests utilizing granular fertilizer this distance may be reduced by one-half. Care must be taken to turn off the dispensing system before the pull up at the end of the test course. Evaluation shall be based on at least three replications of the test. Where possible, each replication shall be made with a single pass of the aircraft in the same direction of travel.

4.3.1 Spray test procedure and sample collectors. An inert or dye tracer material may be added to the contents of the spray tank, or the active chemical may be used as a tracer for the spray pattern tests. Blank formulations or suitable amounts of emulsifier, spreader-stickers and other solvents and carriers shall be included to closely simulate the physical properties of the material to be applied.

4.3.1.1 Quantitative distribution pattern measurement. Distribution pattern measurement techniques may employ discrete sampling targets or a narrow continuous sampling surface placed across the aircraft line of flight. Quantitative analysis of these samples may involve washing techniques or electronic scanning of the sample surface. Collectors shall be selected on the basis of collection efficiency, size and ratio of collection area to accuracy. Collector detail should be reported as outlined in paragraph 6.1.10.

4.3.1.1.1 The pattern may be determined from the amount of tracer material on the targets. Target surfaces that are analyzed by washing techniques should permit all or a constant percentage of the tracer to be removed by a suitable solvent. Washing techniques should insure that only the interior part of containers with raised edges are washed. If the tracer degrades because of exposure to sunlight, passage of time or other factors, the test procedure shall correct for the degradation. Degradation shall be based on tests of the recovery of tracer from targets to which known amounts of the spray liquid have been applied. The exposed surface of individual flat targets shall have an area of at least 50 cm^2 (7.8 $in.^2$). Spacing of the targets across the swath shall not exceed 1 m (3.3 ft). Total length of the sample line resulting from the use of either discrete targets or a continuous surface shall be a minimum of 30 m (100 ft).

4.3.1.1.2 In the event the sample targets are positioned at any angle other than horizontal, all the targets or the entire sample line should feature the same angle of inclination, and this angle should be reported as outlined in paragraph 6.1.10. Care shall be exercised when using sample targets with raised edges to minimize the shadowing effect (the spray droplets approach the target at less than 90 deg) and to make a sample target area correction when converting data to a field area basis.

4.3.1.1.3 For samples that are electronically scanned to measure deposition on the sample surface based on droplet size and numbers, an appropriate area must be scanned to obtain a true representation of the droplet-size distribution in the sample. Also, the spread factor versus droplet size function should be reported for the sampling surface material and the test liquid under test conditions (temperature and relative humidity).

4.3.1.2 Qualitative distribution pattern measurement. A qualitative measure of the distribution pattern may be used to diagnose and correct distribution system deficiencies (plugged or worn nozzles, improper size nozzles, system leaks, improperly placed nozzles, etc.). Qualitative distribution pattern measurement techniques may employ discrete sample targets or a continuous collector placed across the flight line of the aircraft. The measurement technique used should provide a relative or absolute measure of the deposition on the sample surfaces across the flight line.

4.3.2 Dry material test procedure and collectors. Care must be taken to prevent granular materials such as pellets and seeds from bouncing out of or into the collectors. This can be accomplished by collector design or by lining the collectors with material which prevents bouncing and elevating the collectors to prevent granules from bouncing into them. Dust or other small particles may be collected on greased boards or other sticky surfaces or in shallow pans. The area of the top opening of the collectors shall be 0.1 m^2 (1 ft^2) or larger as required to provide a representative sample of the deposit. Spacing of collectors along the swath shall not exceed 1 m (3.3 ft). Particles of material caught may be counted, weighed, or dissolved in a solute for analysis as appropriate.

4.4 Sample analysis and conversion of swath distribution pattern data

4.4.1 Spray pattern test

4.4.1.1 Sample analysis of any type that is compatible with the spray tracer may be used. Examples are validated methods using photoelectric colorimetry, absorption or emission spectroscopy and liquid or gas chromatography. The sensitivity of the analysis shall be at least 1 part per million (ppm). The concentration of tracer in the solvent after a collector is washed in accordance with paragraph 4.3.1.1 may be determined by use of a standard calibration curve developed for the tracer and analytical method employed. The rate of spray deposit on the target collectors in L/ha (gal/acre) may then be determined for each location across the line of target collectors as follows:

$$\text{Target deposit rate} = \frac{K_1 V_t C_t}{C_s A}$$

where

Target deposit rate, L/ha (gal/acre)
K_1 = constant 10^5 (1 657)
A = collector area, cm^2 ($in.^2$)
V_t = volume of solvent used to wash tracer from collector, mL
C_t = concentration of tracer washed from collector, mg/L
C_s = concentration of tracer in original spray solution, mg/L

4.4.1.2 The electronic technique used in the image scanning of discrete or continuous sample surfaces shall result in a droplet-size distribution having a minimum of 20 droplet-size classes. A droplet-size versus spread-factor function over the size range encountered under test conditions for the sample surface material and test liquid shall be developed and used in calculating the deposit volume per unit of area.

4.4.2 Dry material pattern test

4.4.2.1 If the dry material deposited in the collector at each location across the line of collectors is weighed, the deposit rate may be determined in kg/ha (lb/acre) as follows:

$$\text{Deposit rate} = \frac{K_2 W}{AE}$$

where

Deposit rate, kg/ha (lb/acre)
K_2 = constant, 10^5 (13 829)
W = weight collected, g
A = area of collector opening, cm^2 ($in.^2$)
E = collector efficiency, 0-100%

The collectors used should be described as discussed in paragraph 6.1.10.

4.4.2.2 If the physical characteristics of the material collected make counting of individual particles desirable, the results

should be expressed as the number of particles per unit area. Areas should be reported in metric (customary) units. Material collected and weighed should be expressed as weight per unit area. If the material collected is a dust, it may be advantageous to use greased boards or other sticky surfaces or shallow pans filled with a solute for the collectors. Procedures similar to those outlined in paragraph 4.4.1 may be used for analysis of dust deposits collected in solute provided the dust itself can serve as the tracer material or a suitable tracer material is mixed with the dust. The deposit rate should be determined as kg/ha (lb/acre) at each location across the line of collectors.

SECTION 5—TEST RESULTS

5.1 General. Data from the test shall be subjected to a statistical analysis to characterize the distribution pattern uniformity and shall also be presented graphically. Once the maximum effective swath width has been determined, the application rate can be determined.

5.2 Distribution pattern graphing. The data for individual distribution patterns obtained in Section 4—Test Description and Procedure, shall be first graphed as single swath patterns to enable relating the pattern centerline with the aircraft centerline and to show the distribution pattern characteristics. The single swath patterns shall then be graphed as multiple adjacent swaths with additive deposits in the overlapped regions to obtain a composite graph showing simulated field distribution. Since the distribution patterns frequently are not perfectly symmetrical, graphics shall be prepared for both the progressive pass (back and forth) and one-direction pass (racetrack) application methods. If the single swath patterns are skewed due to crosswind, multiple swath graphics may indicate artificial irregularities in the simulated field distribution. Separate graphs shall be prepared for each replication as averaging may mask significant pattern variations. As an alternative to simulated field deposits, actual replicated flight tests may be conducted to present field deposition data from multiple pass applications. Field tests shall be conducted in a suitable manner to construct the multiple pass distribution patterns as described in paragraphs 5.2.2 and 5.2.3.

5.2.1 Single-pass distribution pattern. The measured deposit or relative deposition shall be plotted on the ordinate scale and the target or sample positions on the abscissa scale to the right and left of the aircraft centerline. The graph should show the pattern as the pilot would see it, i.e., with the left-most deposits to the left of the aircraft centerline.

5.2.2 One-direction application distribution pattern. The combined patterns of one-direction passes (racetrack) shall be plotted with the ordinate scale showing the measured deposit rate or relative deposition and the abscissa scale showing the position of the aircraft centerlines and deposit locations. Single-pass distribution patterns shall be plotted around the aircraft centerlines with the pattern centerline being moved a distance equal to the effective swath width. The single-pass distributions and the composite pattern should be shown with each line clearly labeled. Enough patterns should be overlapped to ensure a representative simulated field deposition at least two swath widths in length that would be unaffected by additional swaths (a minimum of four swaths would be needed if the distribution pattern tails extended beyond the centerline of adjacent swaths). The graph should also show the test identification as well as the swath width and coefficient of variation (CV) for the swath width graphed.

5.2.3 Progressive application distribution pattern. The progressive pass distribution shall be plotted with the ordinate scale showing the measured deposit rate of relative deposition and the abscissa scale showing the position of the aircraft centerlines and deposit locations. The graph shall be prepared by the accumulation of deposition at each deposit location for multiple adjacent swaths with the pattern centerline being moved a distance equal to the effective swath width. Every other swath will be the reverse of the single-pass distribution pattern to reflect the field deposits of the back and forth application procedure. Sufficient single swath patterns should be overlapped following this procedure to ensure that the simulated field distribution would be unaffected by additional swaths. A minimum of five swaths would be needed if the distribution pattern tails extend beyond the centerline of adjacent swaths. The single-pass distribution patterns and composite patterns shall be shown with each line clearly labeled. The graph should show the test identification, the swath width and the coefficient of variation (CV) for the swath width graphed. The words "right/right" and "left/left" should also appear to indicate the pattern overlap orientation between the successive pass centerlines.

5.3 Uniformity of distribution. The coefficient of variation (CV) shall be used to determine and express the uniformity of distribution of applications resulting from multiple adjacent swaths. A simulated field application of multiple adjacent swaths using the single-pass distribution patterns obtained in Section 4—Test Description and Procedure, or samples of the deposition from multiple adjacent swaths obtained from actual flight tests will be used to compute the CV.

5.3.1 The mean value, standard deviation, and coefficient of variation (CV) shall be determined as follows:

$$\text{Mean} = \overline{X} = \frac{\Sigma X_i}{n}$$

$$\text{Standard deviation} = \left[\frac{n(\Sigma X_i^2) - (\Sigma X_i)^2}{n(n-1)}\right]^{1/2}$$

$$\text{Coefficient of variation} = \frac{\text{standard deviation x 100}}{\overline{X}}$$

where

$\overline{X}$ = arithmetic mean

X_i = quantified deposit for one collector location for the combined swaths

n = number of collector locations used

5.3.2 Only the central portion of the simulated or measured overlapped field distribution data shall be used to compute the coefficient variation (CV). If the swath spacing is equal to or greater than one-half of the total spread pattern width, this shall include data from one swath centerline to the next for the one direction method of application or the data from the centerline of the first swath to the centerline of the third adjacent swath for the progressive pass method. If the swath spacing is less than one-half of the total spread pattern width, additional overlapped distribution data shall be added until the region for calculation as indicated above would be unaffected by the addition of distribution data resulting from additional overlapping swaths.

5.3.3 Coefficient of variation (CV) calculations. Prior to preparing graphs for paragraphs 5.2.2 and 5.2.3, the coefficient of variation (CV) shall be calculated for both application methods (one-direction pass and progressive pass) for swath centerline spacings ranging from one sampling interval width to the total width of the single swath pattern. Swath increments for this calculation shall not be greater than the sampling interval (or one meter for continuous sampling) across the swath.

5.3.4 Effective swath width. The effective swath width for each method of application can be determined from an inspection of a table as described in paragraph 5.3.3. The largest swath width associated with the minimum acceptable coefficient of variation (CV) shall be considered the effective swath width for the test. An alternative method of determining effective swath width is to determine the distance between the points on either side of the pattern where the rate of deposit equals one-half peak height of that single-pass distribution pattern. Swath width determined by this method should be so stated and the CV computed and reported for both one-direction and progressive pass as outlined in paragraphs 5.2.2 and 5.2.3.

5.3.5 Measured field distributions. If actual flight tests are used to determine field distributions, the line of target collectors must extend at least 3 widths of the effective swath determined in paragraph 5.3.4 and at least 5 adjacent swaths must be flown over the collectors.

5.4 Application rate. The application rate shall be calculated as follows using average values of output rate, ground speed and effective swath width:

$$R = \frac{QK_3}{VS}$$

where

R = application rate, L/ha or kg/ha (gal/acre or lb/acre)
Q = output rate, L/min or kg/min (gal/min or lb/min)
K_3 = constant, 600 (495)
V = ground speed, km/h (mile/h)
S = effective swath width, m (ft)

SECTION 6—REPORTING RESULTS

6.1 **Aircraft and application data.** The following information should be reported:

6.1.1 Aircraft model, type, manufacturer, and year manufactured.

6.1.2 Wing span and type of wing tip spoilers, if used, or any modification of wings.

6.1.3 Engine manufacturer, power rating (normal sea level flight), type of propeller, and engine speed.

6.1.4 Hopper capacity.

6.1.5 Amount of material (dry or liquid) in hopper.

6.1.6 Gross aircraft mass (total mass of the aircraft including pilot, fuel, oil, material, etc., at the time of flight over the line of collectors).

6.1.7 Height of flight above the land surface or crop canopy.

6.1.8 Aircraft indicated airspeed and measured ground speed.

6.1.9 Weather data from paragraphs 3.3 and 4.3.

6.1.10 Size, shape, orientation, material, spacing, number, collection efficiency and height of collectors above or below the land surface or crop canopy.

6.1.11 Type, size, and general description of ground cover or crop where tests are conducted.

6.2 **Liquid dispersal.** The following information shall be reported:

6.2.1 Spray mixture ingredients and proportion for each including physical properties.

6.2.2 Type and size of pump.

6.2.3 Method of driving pump.

6.2.4 Size, type and location of control valves and liquid filters.

6.2.5 Size and type (i.e., round, airfoil, etc.) of boom.

6.2.6 Length of boom and position relative to the trailing edge of the aircraft wing or rotor.

6.2.7 Number, size, type, orientation, arrangement, and condition of atomizing devices. If the atomizer arrangement is not symmetrical, a diagram showing the position of each atomizer relative to the centerline of the aircraft shall be included.

6.2.8 Position of atomizing devices relative to the boom.

6.2.9 Spray pressure and location measured at the boom.

6.3 **Dry material dispersal.** The following information shall be reported:

6.3.1 Manufacturer, type and model of distribution equipment plus a description of any modifications.

6.3.2 Rotor size, configuration and speed of positive metering system.

6.3.3 Dimensions of venturi spreaders such as frontal opening, throat width and depth, width and depth of discharge end, and overall length.

6.3.4 Vane adjustments for venturi spreaders and any modifications from original design.

6.3.5 Rotor size, speed, configuration, and location for centrifugal spreaders.

6.3.6 Manufacturer, type and size of metering gate and gate opening for gravity feed devices and/or agitators.

6.3.7 Name of product, source of supply, particle size, particle shape, bulk density and moisture content of material applied.

6.4 **Calibration and distribution pattern data.** The following information shall be reported:

6.4.1 Method of pattern measurement as described in Section 4—Test Description and Procedure.

6.4.2 Output rate (mean) as determined in paragraphs 4.2.1 or 4.2.2.

6.4.2.1 Length of time interval during material discharge for each test.

6.4.2.2 Amount of liquid or dry material discharged during test run.

6.4.2.3 Amount of liquid or dry material discharged during total test interval.

6.4.3 Graphical presentation of individual single and multiple swath patterns indicated in paragraph 5.2.

6.4.4 Effective swath width as determined in paragraph 5.3.4.

6.4.5 Application rate as determined in paragraph 5.4.

6.4.6 Field application uniformity data, i.e., arithmetic mean, standard deviation and coefficient of variation as determined in paragraph 5.3 (mean values from replicated tests).

Cited Standard:

ASAE S327, Terminology and Definitions for Agricultural Chemical Application